THE STATUS OF SAMPLING PRACTICE IN THE GOLD MINING INDUSTRY IN AFRICA: Working towards an international standard for gold mining sample practices

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DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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ABSTRACT

The status of sampling practices in the Gold Mining Industry in Africa was determined as an initial step in a process to standardise sampling practices in the Mining Industry. Several mines, metallurgical plants and laboratories were visited and the status of equipment, standards and procedures were rated to determine the potential influence of the relevant sampling errors on each component of the particular sampling system. The potential influence of specific management principles was also rated for each of the 21 gold mines visited in Africa. It was concluded that the potential influence of the relevant sampling errors are high in all areas of sampling in this study except for exploration and bullion sampling where it was found to be moderate. The potential influence of management and related principles was rated as moderate. The information deduced from the checklists can be used by each mine in the quest for correct sampling practices and it was applied overall to suggest leading practice procedures for all methods of sampling.

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LIST OF ACRONYMS

Analytical error	AE
Broken ore sample preparation	BOSP
Code of practice	COP
Certified reference material	CRM
Council for Scientific and Industrial Research	CSIR
95% of material will pass through screen aperture	D_{95}
Fifth world conference on sampling and blending	WCSB5
Flame atomic absorption spectrophotometer	FAAS
Fourth world conference on sampling and blending	WCSB4
Fundamental sampling error	FSE
Group and segregation error	GSE
Increment delimitation error	IDE
Increment extraction error	IEE
Increment preparation error	IPE
Increment weighting error	IWE
In-situ nugget effect	INE
Joint Ore Reserves Committee	JORC
Laboratory information management system	LIMS
Mine call factor	MCF
Planned task observation	PTO
Plant call factor	PCF
Process integration error	PIE
Quality assurance and quality control	QAQC
Reverse circulation	RC
Run of mine	ROM
Second world conference on sampling and blending	WCSB2
Shaft call factor	SCF
South African Code for Reporting of Exploration Results, Mineral Resources and Mineral Reserves	SAMREC Code
Standard operating procedure	SOP
Theory of sampling	TOS
Total sampling error	TSE
United States Geological Survey	USGS
University of the Witwatersrand	WITS

1 INTRODUCTION

1.1 Development of the Theory of Sampling

François-Bongarçon (2008) stated in his keynote address at the Sampling Conference in Perth that the Modern Sampling Theory (TOS for Theory of Sampling) can now be seen as going through its golden age. That is sixty years after its inception and after an alternation of periods of admiration and rejection by the industry. Pierre Gy, working as a Chemical Engineer, developed the TOS in the early 1950's when the need arose in the late 1940's. He had to sample a stockpile at a mine in Africa. The principles of the TOS gradually spread from the Mining Industry to other industries, e.g. food, environment, biology, etc.

François-Bongarçon (2008) described the development of the acceptance of the TOS in the Mining Industry where it started in exploration and grade control. It spread to metallurgical plants as a result of training, increased pressure to optimise processes and the development of a new culture. Refineries for precious metals, applications of Quality Assurance and Quality Control (QAQC), sample preparation facilities, assay laboratories, port shipping and commercial sampling followed. It is now part of major resource reporting guidelines namely the South African Code for Reporting of Exploration Results, Mineral Resources and Mineral Reserves (SAMREC Code) and the Australasian Code for the Reporting of Mineral Resources and Ore Reserves by the Joint Ore Reserves Committee (JORC).

1.2 Representative Sampling

Holmes (2009) discussed poor sampling of mineral commodities at the Fourth World Conference on Sampling & Blending (WCSB4). He described the large amount of sampling in the minerals industry and the poor attention that is given to ensure representative sampling despite the availability of training courses, conferences and information on correct sampling practices. He asserted that the responsibility for sampling is often entrusted to personnel who do not appreciate the importance of sampling, with cost being the main factor rather than the representivity of the sample. The quality of the subsequent analysis is undermined and mineral companies are exposed to enormous potential financial losses.

Chieregati and Pitard (2009) explained at WCSB4 that the sampling of gold is one of the greatest challenges in the Mining Industry and that there is probably no other material for which the achievement of sampling precision and accuracy is so critical. The density of gold causes a strong segregation effect as soon as gold is liberated. The consequence is that the gold grade of sub-samples might differ substantially from the primary sample. This problem for the mining company aggravates as the gold grade decreases and becomes marginal and as the distribution of gold in the reef becomes erratic.

1.3 Standardisation

In his article “Sampling: the impact on costs and decision making”, Minnitt (2007) discussed the fact that the simple act of taking a sample implies that someone will use the information contained in the analytical result to make a decision about a course of action. He pointed out that the decisions may involve huge capital commitments for opening or closing a mine or marginal process costs that involve deciding if a load of mineralised rock should be sent to the plant for processing or the waste dump. He stated that sampling is among the most fundamental activities in a mining operation as the possibility exists for large unseen and hidden costs to accumulate in a mineral development because of sampling errors.

Minnitt (2007) said that these hidden costs arise due to misunderstanding of the principle factors that affect the size of sampling errors, such as the mass of the sample, the effects of splitting a sample to reduce the mass and the influence of the nominal particle size. Minnitt believes that a growing understanding and appreciation of sampling theory and methods could lead to a new era for understanding and implementing sampling procedures and protocols. Minnitt suggested in the same article that standardisation through the identification of structural problems and continuous improvement of mining processes should be instituted at a national level in the interests of optimal development of the national patrimony. The author is of the opinion that it is imperative to determine the status of sampling practice in the Mining Industry as an initial step in such a process.

1.4 Mass Measurement

Wortley (2009) discussed the AMIRA P754 Project at WCSB4 in Cape Town and stressed the importance of mass measurement. He explained that the overriding objective of mass measurement for metal accounting is to establish the mass of the particular material or component present at a specific time, or the mass flow of that component over a defined time period, to a distinct accuracy suitable for metal balancing. It is therefore the first measurement in the chain that includes sampling, sample preparation and analysis, each of which introduces its own errors. Mass measurement should therefore be included in an investigation of the status of sampling practice in the Mining Industry.

1.5 Management

In their paper presented at WCSB4 Pollard et al (2009) explained that, from their experience in industry, education, training and professional development, the minerals industry regards sampling as an important part of its operations, but often does not recognize the differences between good and bad sampling practices. They list the reasons as: poor understanding of sampling theory and how it should be applied, a corporate cost saving culture especially concerning technical issues which are not well understood by executive management and a failure in the education of industry professionals to develop an understanding of the fundamentals and economic importance of good sampling practice. The author believes that an appreciation of the involvement and attitude of mine management in terms of sampling practices should also be included in a study of the status of sampling.

1.6 Problem Statement

François-Bongarçon (2008) described how sampling became an irrevocable part of the Mining Industry. Sampling in the Mining Industry starts with exploration and continuous through grade control, mining, metallurgical process, laboratory and ends with the final precious metal product. Sampling is also included in resource reporting guidelines e.g. SAMREC Code and JORC.

The problem is that, although documents were compiled by certain companies to serve as sampling standards (Spangenberg, 2007) or guidelines (Spangenberg, 2008), a comprehensive International Sampling Standard for the Mining Industry does not exist (Minnitt, 2007).

1.7 Purpose of the Study

Chieregati and Pitard (2009) explained that the sampling of gold is one of the greatest challenges in the Mining Industry and that there is probably no other material for which the achievement of sampling precision and accuracy is so critical. Excellence in sampling can only be prescribed by means of a comprehensive document that details all the aspects of sampling.

The purpose of the study is to determine the status of sampling practices in the Gold Mining Industry as an initial step in a process to develop an International Sampling Standard for the Gold Mining Industry.

1.8 Limits of the Research

The research will not just cover sampling per se. Mass measurement is an integral part of sampling and metal accounting and will be included in the study. An appreciation of the involvement and outlook of mine management in terms of sampling practices as explained by Pollard et al (2009) will also be incorporated in the investigation.

The investigation will be limited to gold mines in Africa since there are an adequate number of gold mines available for a study of this nature. The cost involved to visit each mine is a limiting factor.

1.9 Framework

Section 2 is a concise theoretical background that emphasises certain aspects of sampling correctness. The methodology is explained in Section 3. Section 4 presents theory and guidelines relevant to each sampling method, the analysis of the observations made during the visits, the results obtained and a discussion thereof. Conclusive remarks are made in Section 5 while recommendations in terms of leading sampling practices are made in the last section.

2 THEORETICAL BACKGROUND

An investigator requires a thorough understanding of the TOS and extensive practical experience to enable him/her to determine the status of sampling practice in the Mining Industry. Several volumes would be necessary to give a complete literature background on the TOS. The reader is advised to consult the work of Gy (1982) and François-Bongarçon (François-Bongarçon and Gy, 2002) specifically as well as numerous publications by Pitard, Minkkinen, Esbensen, Minnitt and other authors.

The theoretical background conveys certain aspects of sampling correctness that are essential in evaluating potential problems in sampling practices. The sampling errors are listed in this chapter as it is a fundamental part of the investigation. Theory relevant to each sampling method is presented in Section 4.

2.1 Sampling Precision

There are several methods available to determine the precision of sampling. These methods can be divided broadly into theoretical methods based upon probability theory and statistical methods that make no presuppositions regarding the underlying frequency distributions of mineral particles in the ore. When sampling precision is measured, it should be distinguished from the true variability of the process stream.

Instead of using the theoretical formula for calculation of the sampling precision, Gy (1979) derived a model that included the precision of sampling to calculate the probability that particles of mineral, randomly distributed in a host matrix with a specific top size, would be collected in a sample of specific mass. François-Bongarçon rejected the arbitrary formula for the liberation factor of the mineralogical constituents in that model and modified the model (François-Bongarçon and Gy, 2002).

2.2 Sampling Accuracy

Sampling accuracy expresses the absence of bias in the sample mean from the unknown true value. It is usually impossible to experimentally demonstrate the absence of bias. Bias exists if as little as one case of a systematic error is identified.

2.3 Representation

Structural absence of bias should prevail before a sampler is operated. No physical condition should exist that will cause a systematic error and therefore bias, i.e. a condition of sample correctness should prevail. A sample is per definition correct if all the fragments in the bulk to be sampled have the same probability to be selected in the sample (Gy, 1982). The sample will be representative if it is unbiased and has a sufficiently small variance, i.e. sufficient precision.

2.4 Sampling Modes

According to François-Bongarçon (2002) there are three sampling modes corresponding to different types of automatic samplers in a process plant where one-dimensional lots (e.g. broken ore on conveyors and slurry streams) are sampled:

- Taking part of the flow part of the time e.g. internal pipe bleeder, injector- or poppet sampler.
- Taking part of the flow all of the time e.g. in-pipe derivation, pressure bleeder or chute discharge derivation.
- Taking all of the flow part of the time e.g. go-belt- or cross-stream sampler.

Only samplers that comply with the third mode of sampling can guarantee correct samples. The main reason is that even if a totally randomised state could artificially be introduced to the flowing matter just before the sampling point, inserting an obstacle (the collector) into the material will restructure the flow in a precise, deterministic, albeit unpredictable manner. The unknown restructuring result in preferential sampling and it is therefore incorrect.

The same argument applies to manual (grab) sampling. A manual sample taken through a falling flow or from an agitated tank will never be correct because:

- The mechanics of fluids and solids in the vicinity of the collector are modified in an unpredictable manner.
- It is difficult to cut the entire flow.

- It is impossible to execute the cutting movement at an exactly constant speed.

These pitfalls trigger preferential sampling with a biased sample as result.

2.5 Sampling Errors

The Total Sampling Error (TSE) is a summation of all the variances contributed by the error generating components in the sampling system. Contrary to the popular belief that the errors will "average out", sampling errors are additive and not self-compensating. Gy (1979) sub-divided the errors involved in sampling into seven different classes without distinguishing among accuracy, precision of measurement or the natural variability of the material being sampled. These error-classes, as defined by Gy (1979) and sub-divided by Bartlett and Hawkins (1987) are listed in Table 2.1.

Table 2.1 Classes of sampling errors

Type	Gy's notation of errors	Origin of error
Precision	Fundamental Group & segregation Weighting	Particulate nature of ore Inhomogeneous mixing Uneven flow of ore
Natural variability	Long-range quality fluctuation Periodic quality fluctuation	Natural variability Quantities to be measured
Accuracy	Increment delimitation Increment extraction	Incorrect cutter design Incorrect cutter speed

Eleven sources of error have been identified since Gy's initial listing. However, all the errors were implicated by Gy in his analysis although he did not explicitly name them. The sampling errors were discussed by Pitard (2005) at the Second World Conference on Sampling & Blending (WCSB2) in Queensland and lectured in the short course entitled "Sampling Theory and Methods" presented at the University of the Witwatersrand (WITS), South Africa in 2006 (Pitard, 2006). A concise description of the sampling errors is presented here as it is a fundamental part of the investigation.

2.6 List of Sampling Errors

Table 2.2 is a summary of the sampling errors that contribute to the non-representativeness of samples. The sampling errors are grouped according to the factors having the largest effect on them:

Table 2.2 Summary of origins and nature of sampling errors

Origin of errors	Nature of errors	Identity of error
Particulate nature of ore	Distribution of mineral in host rock Compositional heterogeneity Distributional heterogeneity	In-Situ Nugget Effect (INE) Fundamental Sampling Error (FSE) Grouping and Segregation Error (GSE)
Sampling- & sub-sampling equipment Handling of samples & sub-samples	Geometry of outlined increment is not recovered Portion extracted is not the same as delimited increment Non-random variation after extraction Proportional sampling	Increment Delimitation Error (IDE) Increment Extraction Error (IEE) Increment Preparation Error (IPE) Increment Weighting Error (IWE)
Type of sampling process	Small scale variability Large scale non-periodic sampling variability Large scale periodic sampling variability	Process Integration Error (PIE1) Process Integration Error (PIE2) Process Integration Error (PIE3)
Laboratory	Analytical technique	Analytical Error (AE)

2.7 Description of Sampling Errors

2.7.1 Total Sampling Error

The TSE can be separated into components as shown by Gy (1982) and Pitard (2006):

TSE = {INE + FSE + GSE + PIE1 + PIE2 + PIE3} + {IDE + IEE + IWE + IPE + AE}

The first six random errors can never be completely eliminated, but they can be minimized by careful design of the sampling system. The last five sampling errors are sources of bias and can be eliminated. The range of error decreases from the first group (Table 2.2) to the last with typical values of (50–100)%, (10–20)% and (0.1–4)% for the last two groups.

2.7.2 In-Situ Nugget Effect

Pitard (2006) explained during the short course that INE is characteristic to the internal constitution of an ore and arises as a result of the clustering of numerous small gold grains or the occurrence of larger individual grains referred to as nuggets. The uneven distribution of the precious metal in the ore causes difficulty in collecting representative samples.

2.7.3 Fundamental Sampling Error

Minnitt et al (2007a) disaggregate the FSE in its components. When a sample is collected at random, fragment per fragment with the same probability, from a bulk of fragmented material, a sampling error arises between the true grade of the sample and the unknown grade of the bulk. This error is called the FSE and is a minimum in quadratic average for a sample collected under ideal conditions. The error is due to the natural, constitutive heterogeneity of the bulk. The FSE usually has a negligible algebraic mean and is characterised by its variance calculated relative to the true grade of the bulk. In actuality a sample is not collected fragmentally. Successive increments of a certain size are collected. In this case the distributional heterogeneity, i.e. segregation, can diminish the sample reproducibility severely.

The FSE variance as identified by Gy (1982) is the absolute minimum of sampling errors. Esbensen (2008) explained during a short course at WITS that the FSE is the only error that can be estimated before performing the sampling. The FSE arises from the inherent variability of the material being sampled.

François-Bongarçon (2002) described the FSE during a short course presented at WITS as the smallest achievable residual average error, i.e. a loss of precision inherent in the sample due to physical and chemical composition as well as particle size distribution. It arises because of two characteristics of broken ore materials, namely the compositional heterogeneity and the distributional heterogeneity.

The compositional heterogeneity is an indication of the differences in the internal composition between individual fragments of sampled ores as a result of the way they are structured. Distributional heterogeneity represents the difference in average composition of the lot from one position to the next in the lot. It is responsible for the irregular distribution of grade in groups of fragments of broken ore.

2.7.4 Grouping and Segregation Error

Pitard (2006) explained during the short course that the GSE is a natural phenomenon that exists in lots and samples because materials of different densities segregate in a mixture under the force of gravity. The variability of the fragments of a lot comprises of the variability of the increments and the variability between the fragments within the increments. The grouping error can be minimised by collecting as many small increments as possible into a sample. A mathematical development by François-Bongarçon (2002) shows that the increase in sampling variance due to segregation is inversely proportional to the number of increments used to constitute the sample. A sampler should therefore take as many increments as practically possible. The mass of the collected sample should be controlled to maintain the variance below the level considered acceptable. The segregation error can be minimised by homogenising the lot before sampling.

2.7.5 Increment Delimitation Error

Table 2.2 lists the IDE, IEE, IPE and IWE as errors encountered during the practical implementation of a sampling protocol. These errors can be eliminated. Pitard (2006) described the IDE as the difference between the correctly defined size, shape, geometry and morphology of the increment to be extracted and the same four factors of the actual defined increment. The IDE is zero when the collector of the sampler is designed to take a correct sample as per definition in 2.3.

2.7.6 Increment Extraction Error

Pitard (2006) explained that the IEE is the difference between the correctly defined size, shape, geometry and morphology of the increment that should be extracted and the same four factors of the actual extracted increment. The IEE is zero when the collector of the sampler is correctly designed and operated to produce an increment equal to the defined increment.

2.7.7 Increment Preparation Error

The IPE is the sum of the variances introduced by handling of the increment after collection. The factors that may add to the error include contamination, loss, change in composition and non-random interference during transport, drying, screening, crushing, milling and analysis.

2.7.8 Increment Weighting Error

The IWE arises when sampling is not proportional. The variance of the error is a function of the variation in the flow rate of the stream from which the increments are collected. The IWE is zero when the increment weight is constant.

2.7.9 Process Integration Error (PIE1)

PIE1 is small-scale sampling variability introduced as a result of the method used to take a sample. The actual physical sampling process should be flawless when short-range random heterogeneity, which is a fixed property of the stream, is determined. The sampling protocol should be optimised by means of material characterisation and heterogeneity tests. Small-scale variability might mask larger-scale variability if the error is not controlled to an absolute minimum or eliminated.

2.7.10 Process Integration Error (PIE2)

PIE2 is large-scale non-periodic sampling variability introduced by process cycles. Pitard (2006) suggests a number of variographic experiments to establish an optimal protocol for analysing the error namely:

- Optimising sampling intervals
- Optimising the number of increments for composite sampling
- Calculating the TSE

2.7.11 Process Integration Error (PIE3)

PIE3 is large-scale periodic sampling variability introduced by periodic heterogeneity. This long-range cyclic phenomenon may occur as a result of process changes that come about regularly at long intervals. The error can be masked if the sampling frequency is the same as the phase of the cycle.

2.7.12 Analytical Error

Analytical practice may increase accuracy and precision variability due to lack of diligence in procedural steps. Many factors may influence the final result if methods are not meticulously performed e.g. contamination and losses. The selection of inappropriate methods may also contribute to the AE e.g. drying temperature baselines and dissolution techniques.

3 METHODOLOGY

3.1 Sampling Sites

The status of equipment, standards and procedures of sampling for metal accounting purposes in the Gold Mining Industry were determined by visiting 21 mines, associated metallurgical plants and laboratories in Africa (Table 3.1). The names of the companies and of the mines are not listed as the purpose of the study is to get an understanding of the general status of sampling practices.

Table 3.1 Locations of sampling sites visited in Africa

Country in Africa	Exploration	Open-pit	Underground	Metallurgical Plant	Laboratory
South Africa	7		14	13	6
Ghana	2	1	1	2	2
Guinea	1	1		1	1
Mali	2	2		2	2
Namibia	1	1		1	1
Tanzania	1	1		1	1

3.2 Non-disclosure

Agreements of non-disclosure were signed with the four major companies involved. It was concurred that the identities of the mines and associated operations would be protected as the purpose of the study is to get an understanding of the general status of sampling practices. The original audit report of each mine is available for use by the specific mine only.

3.3 Report

The types and methods of sampling found in the main areas where sampling is performed are listed in Table 3.2.

Table 3.2 Sampling categories and methods

Main area	Category of sampling	Method of sampling
Exploration	Drilling	Diamond- and RC-drilling
Mining grade control	Drilling Manual	RC-drilling Chipping
Broken ore	Belt	Stop-belt, go-belt and other
Metallurgical	Pulp Bullion	Cross-stream and other Dipping and drilling
Laboratory	Aliquot selection	Dipping, scooping and other

The sampling methods found in each area are discussed under the following headings in Section 4:

- Literature, i.e. a theoretical study to ascertain which rules and principles define leading practice.
- Guideline, i.e. an outline of required performance derived from the theory and best practice statements.
- Observations, i.e. physical observations at sampling sites measured against the guideline.
- Conclusions which includes suggestions and recommendations for leading practice equipment and procedures.

The observations were evaluated by means of a spread sheet for each mine. The spread sheet was drawn up to rate the potential influence of the relevant sampling errors on each element of the particular sampling system in a specific mining operation. The rating was done on a scale of 1 to 5 with 1 being low, 3 would be medium and 5 is a high potential influence of the sampling errors on the correctness of sampling for the specific element. The completed anonymous spread sheets and a summary sheet are included on a compact disc as Appendix A. The spread sheet is divided into the major areas where sampling is performed:

- Exploration
- Mining, i.e. open-pit- and underground grade control sampling
- Broken ore sampling and preparation, i.e. metallurgical plant feed
- Metallurgical plant, i.e. head-, residue- and bullion sampling
- Laboratory, i.e. aliquot selection during the fluxing process.

The elements of the sampling systems were listed for each area. The sampling errors were also listed so that the potential influence of the relevant sampling errors on each element of the sampling system could be rated. Please refer to 2.7 for a description of the sampling errors.

The following items in the spread sheet are common to all the areas: the “average potential influence” of the relevant sampling errors for the specific sampling element is noted on the right-hand side of the spread sheet. It is an average rating out of 5 which is the maximum potential influence of the sampling errors on the correctness of sampling for the specific element. The average rating is also shown as a percentage. The description under “rating” is derived from the following scale: (0.0–33.3)% is low, (33.4–66.7)% is moderate and (66.8–100.0)% is a high potential influence of the sampling errors on the correctness of sampling for the specific element. An average for the section is also calculated.

The summary sheet shows the average potential influence of the sampling errors on each element of the sampling systems. The averages were calculated from the spread sheets and converted to percentage with 5 being equal to 100%. The part of the summary sheet that is applicable to each area is reproduced for explanatory purposes under each heading in the next section.

The potential influence of specific management principles was also rated for each gold mine. The rating was also done on a scale of 1 to 5 with 1 being low, 3 is medium and 5 would be a high potential influence of the specific management principle on the sampling practice at that mine.

4 INVESTIGATION

4.1 Exploration Sampling

4.1.1 Literature

Storrar (1987:25) says that “sampling is the process of estimating the mineral content and other physical and chemical characteristics of a mass of rock by averaging the characteristics in a number of smaller portions derived from the mass. The mineral content and other characteristics of the smaller portions are obtained by assaying them individually". Exploration samples are collected by means of Reverse Circulation (RC) and diamond core drilling methods. The grade values of the samples are then used in geological and grade models leading to the mineral resource estimate and finally the ore reserve estimate.

According to the TOS a sample is correct if all the fragments in the bulk have the same probability to be selected in the final sample for analysis. It is impossible to estimate the in situ grade of an ore source if this basic rule of correct sampling has to be respected. Pitard (2008) states that the following formula gives the total uncertainty estimation variance σ^2_E when heterogeneous material is drilled, sampled, sub-sampled and assayed:

$$\sigma_E^2 = \frac{\sigma^2}{n} + \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\mathrm{cov}[x_i, x_j]$$

where

$$\frac{\sigma^2}{n}$$

is the variance of the random variability which is introduced during sampling and assaying. These processes should be meticulously controlled to minimise its contribution to the TSE, i.e. the contributions of the IDE, IEE, IPE and IWE. The masses of the sample, sub-sample and aliquot for assay should be carefully considered. The number of increments in the sample, sampling frequency and sample spacing should be optimised to minimise the contribution of this component to the uncertainty.

The second component of the formula is the variance that exists in nature. This non-random variability is characteristic of the ore to be sampled. Pitard (2008) advises that this variability, i.e. INE, FSE and GSE should be well understood to avoid the misclassification of ore. This may be the norm if the sampling and assay errors interfere with the estimation of the non-random variability. An operation may incur large hidden financial losses when the estimation of the true grade is masked by influence of the random variability, i.e. sampling errors introduced by sub-standard sampling practice. Jiménez and Torres (2008) presented an example at the Sampling Conference in Perth of how an incorrect sampling protocol led to the underestimation of gold grade by approximately 27%. Ore that should have reported to the leach pad were classified as waste. The losses are unknown but about US$10 million income was generated within a year after an optimised sampling protocol and operational procedure were implemented.

It is generally accepted that diamond drilling is the best method to extract a representative sample from a deep level although core loss is a relatively common occurrence as explained by Annels and Dominy (2003). They said that a total core recovery of at least 85% and preferably greater than 90% should be achieved for intersections to be used in a resource estimate. Core logging entails the recording of recovery and geological information as well as subsequent sub-sampling of the core.

The importance of accurate core logging is stressed in the SAMREC Code and other codes e.g. JORC. Table 1 of the SAMREC Code (2009) is a high-level checklist of reporting and assessment criteria to be used as a reference by those preparing reports on exploration results. The checklist is not prescriptive but encourages the competent person to report all matters that might materially affect a reader’s understanding or interpretation of the results or estimates being reported. Section T3 on sampling is of particular interest. It lists requirements in terms of sampling governance, sampling method, collection, validation, capture, storage, preparation and analysis.

4.1.2 Guideline

The following elements were included in the checklist as a guideline of good sampling practice:

- Primary sampling: The method should minimise the IDE and IEE. Diamond drilling is the preferred method of extracting deep level samples. The core is extracted in solid state and the resultant influence on the sampling errors is minimal. When the core recovery is less than 100%, it can be managed through proper logging. RC-drilling is used for relatively shallow exploration holes and the method is discussed in detail in 4.2.

- Secondary sampling: Sub-sampling by means of a diamond saw is the accepted method to minimise the IDE and IEE. Although sample loss does occur in the form of sawdust, it is much less than sub-sampling using a guillotine. The shearing force of the guillotine causes the loss of splinters and chips. The geometry of outlined increment is not recovered (IDE) and the portion extracted is not the same as delimited increment (IEE).

- QAQC: Certified Reference Material (CRM) should be included in the batches of samples destined for assay to monitor the accuracy of analysis. Contamination and possible sample swops can be checked by incorporating blanks (barren rock). Duplicate sample values will give an indication of the precision of the analytical process. Duplicate samples should also be submitted to a second laboratory. CRM and blanks must accompany these referee samples. The values will show the relative bias of the operational laboratory compared to the referee laboratory.

4.1.3 Observations

The spread sheet provided for primary- and secondary sampling to be rated. Additional information could also be noted, e.g. the type of reef and QAQC protocol. Table 4.1 is a summary of the average potential influence of the relevant sampling errors on elements of exploration sampling.

Table 4.1 Summary of the average potential influence of specific sampling errors on elements of exploration sampling

	Potential Influence of Sampling Errors : Summary for all Mines													
		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									Average Potential Influence			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
1	EXPLORATION													
	Diamond drilling	3.9	3.0	1.9	1.0	1.9					2.4	5.0	47.1	Moderate
	Other													
	Average for sub-section in %	78.6	60.0	38.6	20.0	38.6							47.1	Moderate
	Sub-sampling													
	diamond saw		3.0	1.9	1.0	2.5	2.4				2.2	5.0	43.4	Moderate
	guillotine													
	other													
	Average for sub-section in %		60.0	38.6	20.0	50.0	48.6						43.4	Moderate
	Average for section in %	78.6	60.0	38.6	20.0	44.3	48.6						**45.3**	**Moderate**
	Note : An empty cell indicates that the element of sampling was not encountered. Potential influence of sampling error is low = 1, medium = 3 or high = 5. (0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high													

Primary Sampling

The spread sheet allowed for the rating of the potential influence of the INE, FSE, GSE, IDE and IEE on the sampling elements, namely diamond drilling and other drilling methods (to be specified when encountered).

Diamond drilling is used as the primary sampling method by all the mines that have exploration programs. The potential influence of the INE varied between moderate and high (3 to 5) depending on the specific reef type and extent of the nugget effect. It is more problematic to sample a narrow composite reef than a wide homogenous reef. The reef type will also have a direct effect on the GSE. The potential influence of the GSE varied from low to high (1 to 4) in correlation with the reef type and nugget effect.

None of the operations have estimated the FSE and the potential influence were rated as moderate for all. The defined increment is usually the same as the actual increment and therefore the potential influence of the IDE was rated as low. The potential influence of the IEE varied between low and high (1 to 4) as the extracted increment differs sometimes from the defined increment especially where carbon leader reef is sampled. A core consisting of this type of reef tends to crumble while a conglomerate will stay intact.

Secondary Sampling

Sub-sampling by means of a diamond saw and guillotine is illustrated in Figure 4.1. The spread sheet provided for the rating of the potential influence of the FSE, GSE, IDE, IEE and IPE on the sub-sampling elements.

Figure 4.1 Sub-sampling by means of a diamond saw (left) and a guillotine (right)

The potential influence of the GSE varied from low to high (1 to 4) depending on the composition of the reef type as explained. None of the operations have estimated the FSE and the potential influence were rated as moderate for all. The defined increment is usually the same as the actual increment and therefore the potential influence of the IDE was rated as low. The potential influence of the IEE varied between moderate and high (2 to 4) as the extracted increment differs sometimes from the defined increment e.g. a carbon leader reef core might disintegrate during sub-sampling as shown in Figure 4.2.

Figure 4.2 Bore core from carbonaceous reef on the left and saprolite on the right

The potential influence of the IPE was rated as moderate (2 to 3) depending on the handling of the increment after collection. Factors that were considered at each operation were contamination, loss and maintaining the sample integrity. Bore cores may be crushed if the trays are stacked directly on top of each other as shown on the left in Figure 4.3. The preferred option is that the trays should be stacked on racks or spaced as shown on the right in Figure 4.3.

Figure 4.3 Bore core trays stacked incorrectly on the left and correctly on the right

The graph in Figure 4.4 shows that the INE and FSE are the main contributors to the moderate potential influence of all the sampling errors.

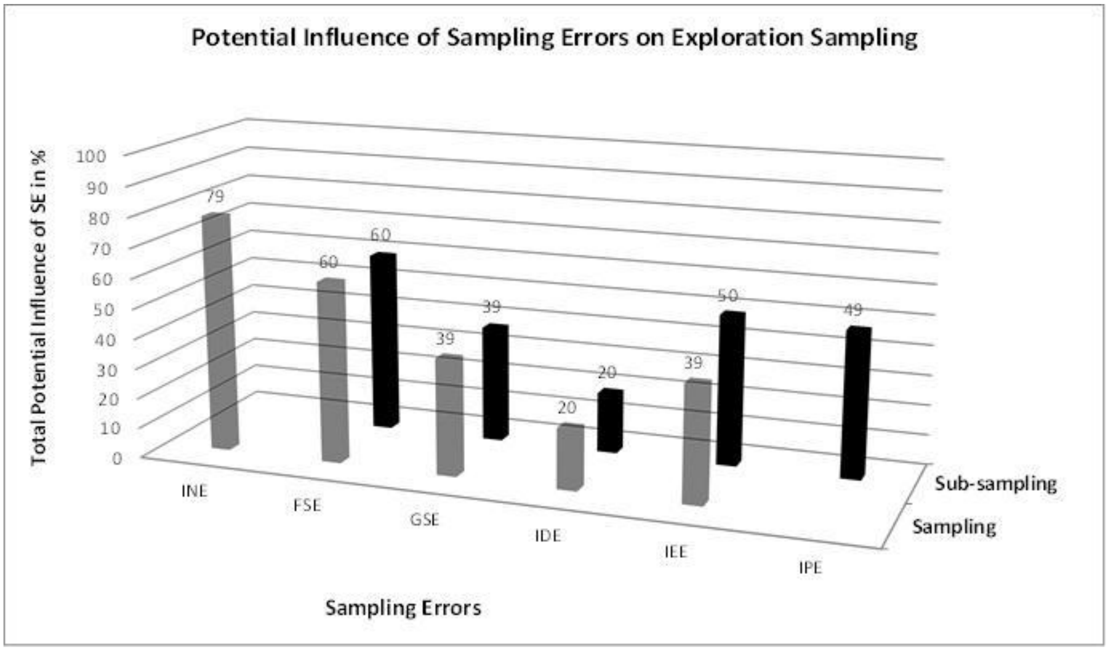

Figure 4.4 Average potential influence of specific sampling errors on sampling and sub-sampling elements of exploration sampling

Information

Information regarding the composition of the reef was recorded to assist in rating the potential influence of the INE and GSE. The nugget effect was noted as well as whether the reef was a narrow composite or a wide homogenous type. The addition of CRM, blanks and duplicates to batches of exploration samples sent for assay were noted in the spread sheets. It was also recorded whether samples were sent to a referee laboratory. All the mines have a QAQC protocol in place. QA is information collected to demonstrate and quantify the reliability of assay data. QC consists of procedures used to maintain a desired level of quality in the assay database.

4.1.4 Conclusions

The in-situ grade of an ore source cannot be assessed if the basic rule of correct sampling has to be respected. Every particle in the ore body does not have the same probability to be selected in the final sample. Therefore, every step possible should be taken to eliminate or minimise the factors that may cause bias in the sampling process.

The INE has the largest potential influence on exploration sampling. The nugget effect is characteristic of the reef and therefore the sampling method has to provide for that e.g. the larger the diameter being drilled the better. Elaborate diamond drilling techniques exist which includes multi-tube wireline systems to extract core in difficult conditions. Boart Longyear™ (2011) was the first diamond drilling exploration product manufacturer to introduce the wireline core retrieval system in 1958. The inner-tube group collects the core sample during the drilling process and is independent of the outer-tube group. These improved methods assist in minimising the potential influence of the IDE and IEE. The FSE has the second largest potential influence and arises from the inherent variability of the material being sampled. The potential influence of the IPE is moderate when solid cores have to be handled and high when fragmented core is extracted from the drill. Splitting of a solid core by means of a diamond saw is easy but sub-sampling of broken or brittle core may be exposed to subjective selection by the geologist. It might be feasible to crush or pulverise a complete increment before splitting.

The decisions that depend on the analytical results of exploration samples usually involve huge amounts of capital. It is therefore of the utmost importance that the very best available equipment should be procured and then used meticulously. It is concluded that:

- Diamond drilling should be used for primary sampling. The largest diameter drill that is practical possible, should be used.

- Secondary sampling should be performed by means of a diamond saw and preferably an automatic unit similar to the automatic core saw that was developed by Almonte Diamond Pty Ltd (2011). Broken or brittle core should be crushed or milled before splitting.

- CRM should be inserted in batches of samples at a rate of not less than 5%. The expected grade range should be covered as well as the 85th percentile of historic values and the cut-off grade. Blank samples consisting of barren material should also be inserted at a rate of 1 in 20.

4.2 Mining

Open pit- and underground grade control sampling were encountered. RC-drilling is the preferred sampling method on surface while chip sampling is used underground.

4.2.1 Literature

Open-pit Grade Control Sampling

Pitard (2005) discusses the many problems that can be encountered when using the RC-drill as a sampling tool, e.g. down-hole contamination, selective separation of particles, partial liberation of minerals and the “plucking effect” are factors that enhance the IEE and consequently the IPE which leads to biased sample values and an estimation error. He shows a correct sampling system for wet RC-drilling which consists of a cyclone, holding tank and rotating secondary sampler. The company, Sandvik Mining and Construction, has patented the RotaPort™ cone splitter for wet and dry RC-drilling and incorporated these elements (Sandvik, 2008).

Pitard (2008) explains that the IDE, IEE, IWE and IPE are sources of bias introduced by the blast hole sampling process. He says that the drilling technique was not designed for sampling purposes. He lists and discusses all the problems encountered during blast hole sampling and the contribution to sampling errors. The conclusion by Pitard is that too many problems are unsolvable and he suggests RC-drilling as an alternative for grade control sampling purposes.

Chieregati et al (2011) explained at the Fifth World Conference on Sampling & Blending (WCSB5) that sample recovery from blast holes is poor and the recovered material often displays particulate segregation and transient mixing phenomena. The loss of fines is a main source of bias. They presented a sectorial sampler which was designed to reduce the loss of fines and thereby increase sampling accuracy for narrow-diameter blast hole sampling. They stated that there are still several unresolved issues but the fine fraction loss issue would appear to be solved for narrow-diameter blast holes and single-discharge drills, while the wide-diameter holes and double-discharge drills constitute a different concept that was not addressed.

Underground Grade Control Sampling

Primary sampling of the exposed reef takes place at the face. The Mine Call Factor (MCF) is the difference between the estimated gold content in the reef and the fine gold produced by the metallurgical plant. A low MCF may be as a result of gold loss due to the physical process, e.g. fine gold bearing material trapped in cracks after blasting and fines lost during cleaning, loading, hoisting, transport and in the extraction process. There may also be an apparent gold loss due to poor sampling. Minnitt (2010) stated in his keynote address at the Sampling Conference in Perth that over-statement of sampling values is the principle contributing factor to apparent loss and low MCF on gold mines where narrow carbon-type reefs are mined.

Sichel (1947) discusses the size of the ideal sample and the sampling interval based on the channel width, variability of the grade and the type of reef. He says that over-estimation can be as much as 100% or more when the softer conglomerate portions of a reef is over-sampled relative to the harder adjacent waste rock. His most significant contribution is the identification of the lognormal distribution for gold assay values. He also describes the bias error in mine sampling theory that can be introduced due to incorrect sample delimitation and incomplete extraction of the sample. These concepts are identical to those identified by Gy (discussed in 2.5) as the IDE and IEE.

The comprehensive work by Storrar (1987) details every aspect of mine sampling including management of sampling crews, tools and equipment, the sampling procedure in general and sample spacing. He stresses the fact that all measurements should be made meticulously and that IDE and IEE should be eliminated. He says that the larger the sample mass, the closer its value will be to the true value of the bulk amount. He lists three factors that influence the representivity of a sampling campaign:

- Distances between samples should be equal.
- Sample masses should be the same.
- The total mass of all the samples should be in relation to the bulk to be sampled.

The all-inclusive article by Cawood (2003) gives an introduction to the MCF and an overview on how to conduct related investigations. The paper concentrates on the importance of sampling standards for narrow gold reefs by presenting an overview of the development of sampling standards in South Africa. His literature survey revealed that reef gold content may be over-estimated by as much as 30% as a result of traditional sampling methods and the characteristics of narrow carboniferous-type reefs.

A preliminary report by François-Bongarçon (2012) states that face sampling can be discarded as a source of biased reconciliations after an investigation into the factors that could influence the MCF at a narrow reef gold mine in the Orkney area. Assay values of core samples (also called coffin samples) were compared to corresponding chip sample values and it was concluded that no systematic bias can be found in the latter sampling method. It is expected that the bias introduced when sampling wide homogenous reefs, e.g. Ventersdorp Contact Reef and Main Reef, will be less significant than the bias introduced when sampling narrow composite reef, e.g. Carbon Leader, Basal Reef and Vaal Reef. This type of reef consists of a pebble conglomerate and a very thin carboniferous layer which is less than 20mm wide at the base of the reef. The latter is much softer than the conglomerates and contains up to 90% of the gold mineralisation.

Chip sampling is the most common method used for underground grade control sampling. Magri and McKenna (1986) completed a geostatistical study of diamond-saw sampling, also called coffin sampling, versus chip sampling. They concluded that diamond-saw sampling is a significantly better method than normal production chip sampling to reduce the IDE and IEE.

Storrar (1987) refers to Sichel and Rowland (1961) when he compares hand sampling to machine sampling. He says that a cautiously planned experiment showed that the precision of hand sampling compares well to that of machine sampling. He adds that machine sampling is costly, requires a skilled operator and is problematic in the workplace in terms of services.

Lerm (1994) established in a study of conventional chip sampling of narrow carboniferous reefs that uniform sample extraction is almost impossible in spite of attentive supervision. The difference in hardness between the conglomerate and carbonaceous material may cause a 20% oversampling of the softer compound. Mohapi et al (2011) investigated the possible existence of a sampling error and resultant bias related to the chip sampling practices at a narrow reef mine. The quality of the actual chip sample produced from underground was assessed versus the required sample according to the sampling procedure of the mine as compiled by Kelly (2006). The chip sampled face was evaluated by means of a mould and the observations proved the chip sampling to be sub-standard. The observations were further examined by comparisons between the chip sample values and core sample values. The core samples were cut to size as required by the procedure of the mine. It was found that the chip samples are unbalanced, irregular and not compliant to the standard of the mine and this was also observed during the chip sampling practices. The statistics confirmed the observations. It was concluded that, although the historical chip sampling values returned higher estimates, the result will be treated as indicative and not conclusive due to the limited number of coffin samples taken.

After visiting the underground face sampling areas of five mines, Prinsloo (2012) confirmed in an internal report that the delimited sample is almost never extracted as different rock types will either result in over- or under sampling. The IDE and IEE are always prominent in a production environment where time is of the essence. Flitton (2009), Mohapi (2011) and Prinsloo (2012) and emphasise the fact that chip sampling is operator dependant. The operator should be motivated, trained and encouraged to maintain a high standard in sampling practice. This has been noted long ago by Beringer (1938) who described the chip sampling method on the Witwatersrand as well as the role and qualifications of a good sampler who should be technically trained and honest.

The historical development of sampling practice on South African mines as compiled by Cawood (2003) shows that the complete spectrum of sampling errors were identified, appreciated and accounted for in the principles of underground sampling practice. He noted a number of lessons learnt in the evolution of mine sampling practice. One of the lessons is in contrast to the propagation of Beringer (1938) who envisaged a single standard protocol for all mines to ensure that samples through the mining industry are comparable. The lesson is that "there should be different standards for different gold mineralizations when considering sampling protocols" (Cawood, 2003:222).

Several mining companies endeavoured to find alternative underground sampling methods. Lerm (1994) discusses the research on non-destructive radiation methods of analysis of the stope face. Internal reports show that Anglogold Ashanti made numerous attempts to find replacements for sampling and assaying for gold and uranium by measuring the natural gamma radiation emitted by Uranium, Thorium and Potassium to give an inferred gold value in real time. All the reports recommended that the scanners should not be used to replace conventional sampling and assay methods (Rambuda, 1999; Kirchner, 2009). It was found that the calibration curve of the scanner had to be updated continuously, the variance between the predicted gold grade and the assayed grade was inconsistent and the correlation between uranium counts and assayed uranium values was low.

Harrison (1952) discusses the tendency to over-sample and consequently over-estimate sample values of narrow reefs. He suggests the replacement of chip sampling by diamond drill sample methods. Core drilling, e.g. diamond drilling and fines drilling, e.g. the "sampdril" as described by Pitard (2006) are efficient sampling methods to eliminate the IDE and IEE. Unfortunately many environmental factors, e.g. noise, dust and energy-supply to the drill prohibit the implementation of drilling as a sampling method. The possible presence of methane rules out electricity as a source of energy. Noise and dust containment are problematic when pneumatic drills are used.

A disk cutter was developed by the CSIR in conjunction with Anglogold Ashanti (Barnard, 2005) in another attempt to find an alternative underground sampling method to eliminate all sources of bias that contribute to the IDE, IEE, IPE and IWE. The cutter is a pneumatic tool that was developed to cut the reef at an even depth across the face and produce dust. A single or double disk would be ideal in terms of the delimitation of the sample. Collection of the dust generated by the grinding discs would constitute the sample. It was imagined that more, closer spaced samples could be collected and that would be more representative than before. The process would also eliminate preparation by the laboratory, i.e. drying and milling which would improve the turn-around time.

Unfortunately the final solution has not been found yet as all the environmental and health and safety requirements could not be satisfied. The principle finding by the risk assessment was that the grinding of the discs would be a significant source of noise induced hearing loss for the operators. It was predicted that the cutting disk would reach 118dB underground. The operators would need to be made aware of the risks posed and would be required to use a combination of high-quality ear plugs and earmuffs to limit their effective exposure levels.

The idea was to collect the dust from the cut channels in a flammable bag. The bag would be assayed complete with the dust sample. The test work determined that utilisation of the tool could potentially result in respiratory dust exposure concentrations above the international acceptable standard of 1.00mg/m^3. This was a concern, not just because of the additional dust exposure, but it also means that a representative sample is not being collected.

The question of a bias free underground sampling tool remains unanswered. The underground sample values may be biased but the effect is reduced by the fact that thousands of samples are collected and the values used via a Kriging process to model the ore body.

Dominy (2009) reported at WCSB4 that grab samples are collected in some mines as a method of grade control sampling. He listed many factors that contribute to the FSE, GSE, IDE and IEE. It is generally accepted that the value of a grab sample is only applicable to the aliquot that was assayed. Grab sampling is the least preferred sampling method.

4.2.2 Guideline

Open-pit Grade Control Sampling

Primary sampling

It is generally accepted that a RC-drill equipped with a cyclone, a drop box, a stationary cone splitter with rotating radial collectors and an emission filter is the best method to do grade control sampling. A well-equipped RC-drill can be seen in Figure 4.5. The best method to extract a representative sample from a deep level, diamond drilling, is slow and expensive. Blast hole sampling and sub-sampling by means of radial collectors are the least preferred options for several reasons as explained by Pitard (2008).

Figure 4.5 RC-drill in operation

Secondary sampling

Several sub-sampling methods are available. It is generally accepted that the stationary cone splitter with rotating radial collectors is the best method to split the fines and rock chips collected by the cyclone of the RC-drill. Sandvik (2008) describes the interaction between the cyclone and splitter. The drop box collects the sample during drilling of a specific interval, shuts off the flow to the box at the end of the interval and drops the sample onto the cone under the force of gravity only. The rotating collectors collect the sub-sample. Sticky ore e.g. saprolitic rock types might accumulate on the radial cutters of the cone splitter. Obstructed cutter openings will produce biased sub-samples. Compounds that inhibit sub-sampling are usually collected per increment via the cyclone and sun-dried before splitting by means of a riffle splitter.

A riffle splitter is normally used when the more expensive stationary cone splitter with rotating collectors is unavailable. It is also used when wet samples extracted from the pit have to be dried before sub-sampling. The riffle splitter is habitually utilized incorrectly as minimal time is spent on the procedure. An example of an incorrect procedure can be seen in Figure 4.6 where the sample is dispensed from the bag into the splitter instead of using a bin or tray of the same dimensions as the splitter. This practice may lead to spillage and subsequent bias of the sub-sample. The bent vanes of the three-tier splitter are also shown in Figure 4.6. This condition promotes the IDE. Sometimes a sample is too small to be put through a splitter, typically at the beginning of a hole, or the samples are too moist and sticky to go through a dry splitter and not wet enough to go through a wet splitter. Three-tier splitters are biased as the increment from the same side is split again, i.e. preferential sampling. It is evident that the IDE and IEE have large potential influences on sub-sampling when the riffle splitter is used.

Figure 4.6 The three-tier riffle splitter on the left is used incorrectly for sub-sampling on the right

The following sub-sampling equipment have inherent flaws and should rather be avoided:

- A stationary cone splitter with stationary collectors as the cone has to be level to eliminate the possibility of preferential sampling. Rotating collectors as shown in Figures 4.5 & 4.7 (right) assist in taking representative samples when the levelling is imperfect.

- A rotating cone splitter with rotating or stationary collectors because the rotating cone imparts a momentum other than the sole acceleration of gravity on the sampled material, resulting in complex and uncontrollable flow mechanics and a biased sample.

- A stationary or rotating cone with slots in the cone as shown in Figure 4.7 (left) for the reasons listed above and the consequential biased sample.

Figure 4.7 A slotted rotating cone on the left and one radial collector already inserted in the stationary cone splitter with rotating collectors on the right

Underground Grade Control Sampling

Cawood (2003) makes recommendations for consideration in terms of the current sampling protocol for narrow-reef mines. The Anglogold Ashanti standard for underground chip sampling (Flitton, 2009) was used as a guideline in evaluation the sampling methods (please see 4.2.4 for detail). The chip sample taken from the face is prepared in its entirety as it usually weighs less than 500g, i.e. no sub-sampling is performed before crushing and milling. Lyman and Simonato (2008) discussed the variable split sample divider at the Sampling Conference in Perth. The apparatus can be used to collect a specific mass fraction from the original sample after crushing.

4.2.3 Observations

The spread sheet provided for several elements of open-pit mining grade control sampling to be rated as shown in Table 4.2. Grade control sampling is performed by means of RC-drilling at all sites visited.

Table 4.2 Summary of the average potential influence of specific sampling errors on elements of open-pit grade control sampling

		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									Average Potential Influence			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
2	**MINING**													
2.1	**Open-pit grade control sampling**													
	Diamond drilling													
	Blast hole sampling													
	RC drilling	4.3	5.0	5.0	3.0	5.0					4.5	5.0	89.3	High
	Other													
	Average for sub-section in %	86.7	100.0	100.0	60.0	100.0							89.3	High
	Sub-sampling													
	diamond saw													
	guillotine													
	radial collectors													
	riffler		3.0	3.7	5.0	5.0	5.0				4.3	5.0	86.7	High
	rotary cone - stationary collectors													
	rotary cone - rotating collectors													
	rotary cone - slots													
	stationary cone - stationary collectors		3.0	5.0	3.0	2.0	4.0				3.4	5.0	68.0	High
	stationary cone - rotating collectors		3.0	3.0	2.0	2.0	1.0				2.2	5.0	44.0	Moderate
	stationary cone - slots													
	other													
	Average for sub-section in %		60.0	77.8	66.7	60.0	66.7						66.2	Moderate
	Average for section in %	86.7	80.0	83.3	65.0	70.0	66.7						**77.8**	**High**

Note : An empty cell indicates that the element of sampling was not encountered.
Potential influence of sampling error is low = 1, medium = 3 or high = 5.
(0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high

Riffle splitters are used by 50% of the mines to do sub-sampling. The IDE, IEE and IPE have a total high potential influence on the correctness of sub-sampling. One operation uses a stationary cone splitter with stationary collectors. At this particular operation the potential influence of the sampling errors was rated as high. Stationary cone splitters with rotating collectors are used by 33% of the mines. At these operations the potential influence of the sampling errors was rated as moderate with the FSE and GSE as the main contributors. Table 4.2 is a summary of the average potential influence of the relevant sampling errors on elements of open-pit grade control sampling.

Open Pit One

RC-drilling and sampling are carried out in the pit. A grade control sample is collected per meter drilled. Duplicate samples are collected every 10m of the 30m deep holes which are 5m apart. Each sample is collected in a bar coded plastic bag that is attached to one collector of the cone splitter as displayed in Figure 4.8. Two bags are secured on both collectors for duplicate sample taking. Sample loss occurs as some material is blasted from the hole and not collected via the cyclone (Figure 4.8).

Figure 4.8 A stationary cone splitter on the left and particles blasted from the RC-drill hole on the right

The bar codes of the grade control samples are recorded. Blanks and CRM are inserted in every batch of samples before dispatch to the laboratory.

The cyclone discharges directly into the cone splitter during drilling. The cyclone pressure varies and a momentum other than the sole acceleration of gravity is imparted on the flow of particles. This will result in preferential and therefore incorrect sampling. The sample bag is replaced without interruption of the drilling process and the flow to the cyclone.

The correct procedure is to close the spade valve between the cyclone and the cone splitter until a meter is drilled. The air flow to the cyclone should then be stopped, the valve opened and the sample dropped into the cone splitter to be sub-sampled. The sample bag should then be removed before pressurized air is used to blow the cyclone and cone splitter clean.

Open Pit Two

The drilling procedure is the same as for Open Pit One with the exception that the sample is collected via the cyclone and then riffle split. The RC-drill discharged into a cyclone that was closed at the bottom. A sample is collected after each rod length of 6m is drilled, riffle split and bagged. The procedure requires that samples should be collected per meter intervals. The following pictures in Figure 4.9 exhibit the sampling process and the fact that the bag was only removed after the drilling of a complete rod length:

Figure 4.9 Sampling process at Open Pit Two

Figure 4.10 show that the three-stage riffle splitter is not used as per the operating standard, i.e. the primary sample is not evenly fed via a pan to the riffle splitter. This will result in preferential and therefore incorrect sampling. It should also be noted that a multi-stage riffler is biased by design as the sub-sample from the same side is always selected for splitting in the next step. The poor condition of the three-stage splitter can also be seen in Figure 4.10. Sub-sample loss occurs through the damaged chute.

Figure 4.10 Sub-sampling by means of a damaged three-stage riffle splitter

Open Pit Three

A Sandvik RotaPort™ cone splitter as shown in Figure 4.5 is mounted on the RC-drill rig for grade control sampling purposes. The material is directed from the drill via a cyclone to a drop box which delivers meter increments to the splitter without introducing a bias in the feed flow. The splitter is designed for both dry and wet drill sampling.

The sample bags are loaded into radial shaped collectors that rotate inside the splitter during operation. This prevents interference from outside elements during sampling, tearing of bags and sample loss. The labelled bags are loaded into the collectors away from the machine. The rotating collectors are quick release, fully guarded and safety interlocked. Up to four samples can be taken simultaneously via the radial cutters with options to change split percentages by changing cutters. The sampler cone is stationary and only the cutting ports rotate. Therefore the feed material flows off the cone without spiralling. It ensures that a true 360º rotational sample cut is taken per revolution.

An emission filter prevents harmful dust emissions from entering the atmosphere during the drilling process. The operator uses compressed air to clean the equipment thoroughly after each increment drilled. A mass balance is carried out at every 20th hole. The grade control samples are bar coded. Duplicates are labelled by marking pen. Blanks and CRM are inserted in each batch of samples before dispatch to the laboratory. The Sandvik RotaPort™ cone splitter that is mounted on the RC-drill rig for sampling purposes is state of the art equipment. No deviation from the standard operating procedure could be found.

Summary

The average potential influence of the sampling errors was rated as high at 77.8% on elements of open-pit grade control sampling. Figure 4.11 shows that the high influence of the sampling errors is a result of the large contributions of the INE, FSE, GSE and IEE.

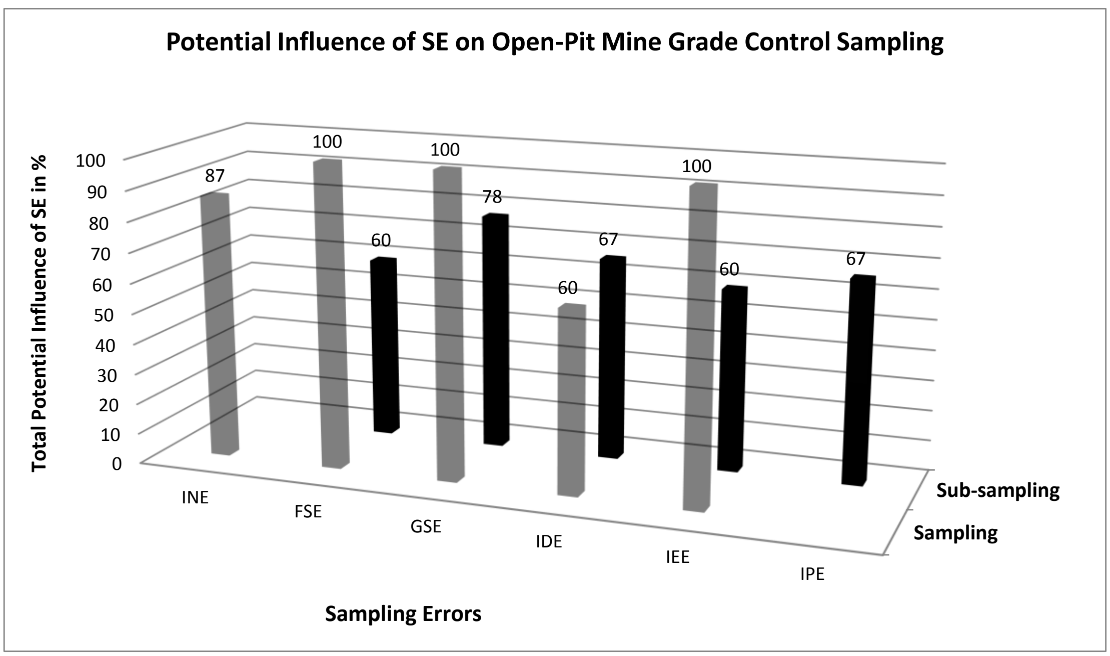

Figure 4.11 Average potential influence of specific sampling errors on sampling and sub-sampling elements of open-pit grade control sampling

Underground Grade Control Sampling

The spread sheet provided for the elements of underground mining grade control sampling to be rated as shown in Table 4.3.

Table 4.3 Summary of the average potential influence of specific SE on elements of underground grade control sampling

		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									Average Potential Influence			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
2	**MINING**													
2.2	**Underground grade control sampling**													
	Grab													
	Chip	4.8	3.0	3.0	5.0	5.0					4.2	5.0	83.2	High
	Coffin													
	Drill: core													
	fines													
	Other													
	Average for sub-section in %	96.0	60.0	60.0	100.0	100.0							83.2	High
	Sub-sampling													
	diamond saw													
	guillotine													
	riffler		3.0	3.0	5.0	5.0	5.0				4.2	5.0	84.0	High
	cascade rotary splitter													
	other													
	Average for sub-section in %		60.0	60.0	100.0	100.0	100.0						84.0	High
	Average for section in %	96.0	60.0	60.0	100.0	100.0	100.0						**83.6**	**High**

Note : An empty cell indicates that the element of sampling was not encountered.
Potential influence of sampling error is low = 1, medium = 3 or high = 5.
(0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high

Prinsloo (2012) compiled the observations of the underground visits following the operating procedure as described in the Anglogold Ashanti standard document (Flitton, 2009):

- The area to be sampled was not always washed down and cleaned of loose rocks.
- Panels are sampled after 5m of face advance.
- Demarcation of sample length and width was at all times performed according to the standard.
- Chipping of the demarcated area presented many problems, e.g. sample loss and incomplete or excessive increment removal.

- Duplicate bar coded sample labels were used. One label was placed inside the bag and another was adhered to the bag.
- Each sample bag was rolled up and secured with a rubber band.
- All sample labels were recorded before the samples were transported to surface.
- QAQC material in the form of CRM and blanks were inserted in the batch of samples before dispatch to the laboratory. The rate of QAQC material addition is 5%. The samples are transported in a locked container.
- All personnel are not well acquainted with the requirements of the standard.

All the mines do grade control sampling by means of chip sampling. The INE, IDE and IEE play major roles in the poor performance of this sampling method as presented by the graph in Figure 4.12. The potential influence of the sampling errors was rated as high.

One mine sub-samples the primary chip samples using a riffle splitter. The potential influence of the sampling errors consisting mainly of the IDE, IEE and IPE was rated as high for this particular operation. All the other mines submit the complete primary sample to the laboratory where the total sample is milled before sub-sampling. All the operations include reference material in the batches of samples sent for assay. Table 4.3 is a summary of the average potential influence of the relevant sampling errors on elements of underground grade control sampling. The average potential influence of the sampling errors was rated as high at 83.6% on elements of underground grade control sampling.

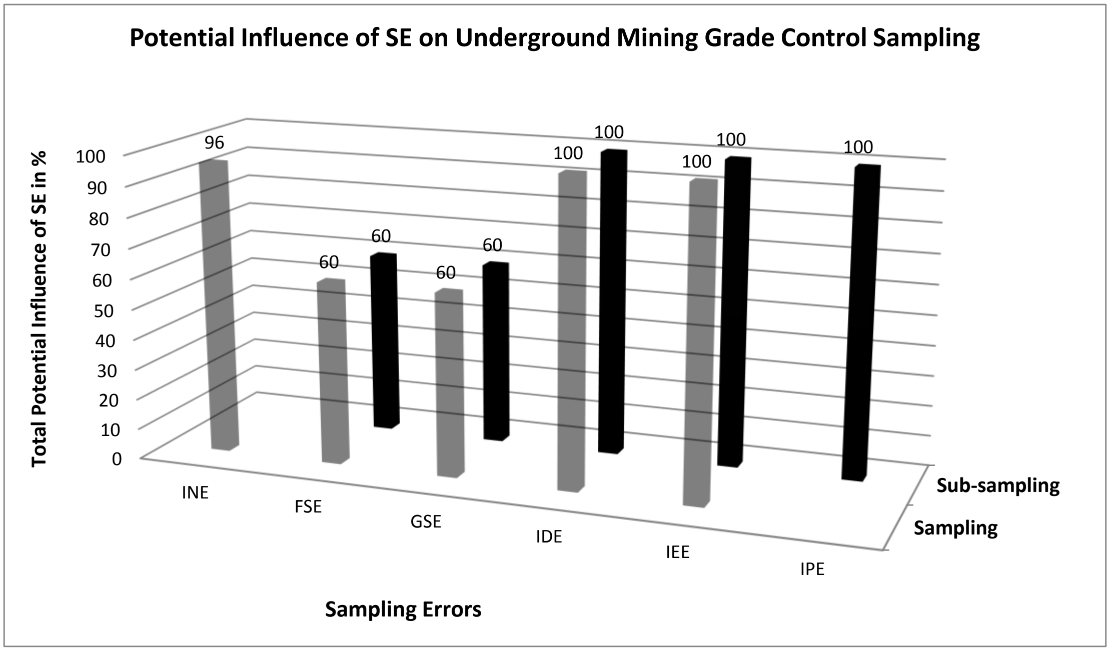

Figure 4.12 Average potential influence of specific sampling errors on sampling and sub-sampling elements of underground grade control sampling

Mine Sample Preparation and Assay

The assay procedure is almost the same for all grade control samples. Some operations prefer a gravimetric finish while others rely on Flame Atomic Absorption Spectrophotometer (FAAS). An overview of a visit is presented to allow an understanding of the general procedure.

Sample receipt

Grade control samples from the mining operations are delivered in plastic bags as displayed in Figure 4.13. Metal tags inside the bags identify the samples. Some mines use bar code labels. A list of the samples submitted to the laboratory accompanies every batch. The chain of custody is maintained by signature throughout the different analytical processes. Scanning of the bar code labels speeds up sample reception and transfer of the sample identities to the Laboratory Information Management System (LIMS).

Figure 4.13 Sample submission list accompanying the RC-drill samples

Drying

The samples are transferred to metal dishes. The samples are dried at ±190°C although the set value is only 150°C as shown in Figure 4.14. Digital temperature gauges are positioned at each oven. The drying temperature is a controversial point and every laboratory use a different set value. The drying oven temperature should be maintained at 100°C ± 10°C so that the composition of the ore is not altered (Lenahan and Murray-Smith, 1986). It is good practice to check the oven temperature with a pyrometer to verify the temperature gauge display. The instruments should be calibrated when there is such a large difference between the set value and the actual value as displayed on the far right picture in Figure 4.14.

Figure 4.14 Metal tag in sample dish and temperature gauges

Crushing, splitting and milling

The product of the primary crusher passes 8mm. The crusher is cleaned by air. Blank material is crushed after every tenth sample and submitted for assay to check for residual material that may cause carry-over contamination. The sample is split by a 12-vane riffler as pictured in Figure 4.15. The splitting is repeated, if necessary, until the mass is ±300g. The sample is milled in a LM2 mill to 90% passing 75µm. The bowl and puck are cleaned by brush and air. River sand is used to clean out "sticky" material.

Figure 4.15 Riffle splitter, LM2-mill and pulverised sample in mill bowl

In this case the riffler is in a poor condition and a source of cross-contamination. A riffler should be used correctly, i.e. the material should be evenly spread on a pan for delivery to the riffler. François-Bongarçon (2002) explained during a short course presented at WITS that the variance of a riffler is ±100% compared to ±2% of a rotary splitter. However, it is time consuming to use a rotary splitter if a large amount of samples has to be processed.

The Laboratory Guideline (Maree, 2007) recommends the use of a ten-way cascade rotary splitter to reduce sample size. The cup divider should run at an angular speed of less than 0.6m/s. The vibration of the feeder should be moderate to ensure an even flow of material with a bed thickness of ±5mm. Right-angled dividers should be installed between the sub-sample collectors to minimize spillage. Diagonally opposite cups are combined to obtain sufficient sample. The feed hopper, launder and collectors are cleaned between samples using compressed air.

Fluxing

Fusion crucibles are used more than once at the specific laboratory. Some crucibles were in a poor condition. Each crucible is lined with a plastic bag as presented in Figure 4.16. Flux is measured by scoop. A broad bladed spatula is used to remove the sample from the tilted packet. Silver nitrate is added by means of a calibrated dispenser.

Figure 4.16 Fluxing process

Fusion

Each tray containing 50 samples is multi-loaded into the gas-fired furnace (Figure 4.17). The temperature controller is set at 1100°C. The operating temperature was ±1000°C. Lenahan and Murray-Smith (1986) recommend a gradual increase to 1100°C. The Laboratory Guideline (Maree, 2007) states that the furnaces should operate at a temperature of 1075°C ± 25°C which is required for a complete fusion. A multi-pour was witnessed as shown by the picture in the middle. The quality of the fusion was good as indicated by the cob-web on the slag in the picture on the right.

Figure 4.17 Multi-loading, multi-pouring and a cob-web in the slag

The furnace door was closed twice during pouring to allow the fusion furnace to regain temperature. Lead spillage was recorded by the spotter and the specific sample marked for repeat. Figure 4.18 shows the spill during pouring and the lead on the mould. The lead might contain gold resulting in an negative biased assay value.

Figure 4.18 Pouring of melt and lead spillage

De-slagging

Some of the lead buttons are mass measured to check if the required mass of lead is obtained. The operator does not use a forceps to hold the button being hammered and may be injured. Figure 4.19 displays the de-slagging method. The lead button should be hammered in such a way as to get rid of all the slag. Slag remaining on the button will cause pitting of the cupel and subsequent loss of gold from the prill. However, the opposite is also true – the slag may enclose the prill so that it cannot be recovered from the cupel.

Figure 4.19 De-slagging

Cupellation

The first picture in Figure 4.20 shows that the cupels were pre-heated. Moisture might be captured in the cupels if they are not preheated. As a result the cupels could be brittle and break in the muffle. The escaping moisture may also cause spitting as the temperature increases resulting in loss of lead. The tray was allowed to cool, second picture, before the lead buttons were transferred to the cupels (third picture). The tray was loaded into the cupellation furnace at a temperature of ±1000°C.

Figure 4.20 Cupellation process

The copper pattern was checked once again after cupellation and the beads were transferred to the test tubes. The dark coloured cupels in Figure 4.21 displays the copper pattern. This indicates the first sample and assists in the correct positioning of the tray.

Figure 4.21 Cupels with beads and beads being transferred to test tubes

Dissolution

The racked test tubes are heated directly on a hot plate as shown in Figure 4.22. It is good practice to use a temperature controlled water bath to heat the acid in the test tubes. The second picture in Figure 4.22 displays the gravimetrically confirmed dispensers that are used for acid volume measurement as final volumes can be better controlled. It is evident from the picture on the right that labeling of dispensers need urgent attention as all chemicals should always be clearly marked.

Figure 4.22 Dissolution process

Evaluation

The final evaluation is performed by means of FAAS. Figure 4.23 shows that the preparation- and expiry date, value of the standard and the signature of the analyst appears on the label of the standards used for FAAS.

Figure 4.23 Evaluation by Flame Atomic Absorption Spectrophotometer

A primary control standard is prepared from 99.99% gold plate or gold wire. This standard and a blank are read before each tray of samples. FAAS maintenance, e.g. cleaning of the nebuliser, burner and spray chamber are carried out according to a planned maintenance program.

Quality control

The following quality control samples are included in every batch of 50 samples:

- Coarse blank – monitoring contamination in crushing.
- Crushed blank – monitoring contamination in milling.
- Flux blank – monitoring possible contamination of the flux and sample swaps.
- Standard reference material – to determine accuracy of assay.
- Duplicates – to determine precision of assay.

The CRM in the 2.5kg jars is segregated. A batch of CRM is split by means of a cascade rotary splitter to the required aliquot amount. The aliquots are stored in envelopes or banker’s type plastic bags, i.e. “ziplock” plastic bags.

4.2.4 Conclusions

General

Correct sampling procedures will produce unbiased samples. A slight modification to the procedure at Open Pit One will eliminate some of the factors which cause a bias in the sample value. The procedure should be modified to allow the sample to drop into the cone splitter just under gravitational acceleration, i.e. stop the air flow after drilling, open the spade valve to drop the sample via the splitter into the bag, remove the bag, start the air flow to clean the cyclone and splitter, close the spade valve and continue drilling of the next interval.

Obvious sampling errors should be eliminated e.g. sample loss as a result of using damaged equipment, spillage during sample handling and breach of sampling procedure. Equipment that was not designed according to the TOS should be replaced e.g. the multi-stage riffle splitter at Open Pit Two. Figure 4.24 is a picture of a riffler that will produce unbiased sub-samples when a proper procedure is followed. The trap door of the loading pan opens from the centre line.

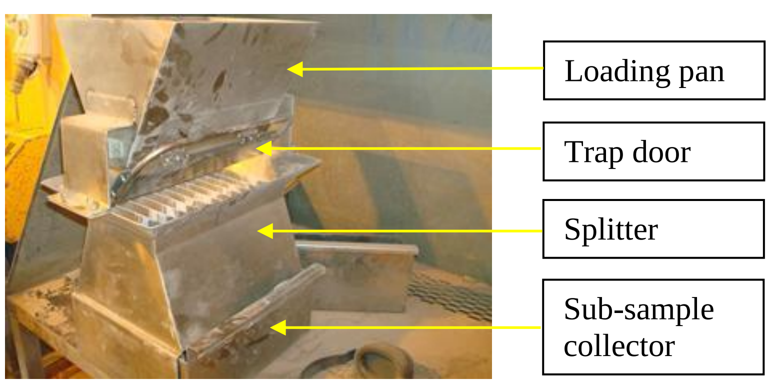

Figure 4.24 Riffle splitter with fixed loading pan

Open-pit Grade Control Sampling

The INE, FSE and GSE have high potential influences on open-pit grade control sampling. The RC-drilling method is generally used for grade control sampling. It is a robust sampling technique that produces rock chips. Particles outside the delimited area may be dislodged by the air pressure and added to the sample, i.e. contributing to the potential influence of the IDE and IEE. Reflux may occur during the addition of drill rods causing asymmetric distributions of grade (previous increment contaminating the following) and symmetrically spaced spikes in grade, i.e. increasing the potential influence of the IEE.

The INE and FSE have a similar effect as for exploration sampling. The potential influence of the GSE is inflated by the variability between the increments. The transport of the rock chips by air pressure and the fact that an increment cannot be exactly defined enhances segregation. The potential influence of the IPE can be minimised by reducing the effect of human interference during the sub-sampling process. Semi-automated equipment, e.g. the fixed cone splitter with rotating collectors, can be used instead of the riffle splitter.

The decisions that depend on the analytical results of grade control samples usually involve immediate mining decisions, i.e. whether the material should be delivered to the metallurgical plant or to the waste rock dump. It is therefore of the utmost importance that the very best available equipment should be procured and then used meticulously. It is concluded that:

- Primary sampling. RC-drilling should be used for primary sampling. Pitard (2008) lists many advantages of RC-drilling.

- Secondary sampling. The drill rig should be equipped with with a cyclone, a drop box and an emission filter. A stationary cone splitter with rotating radial collectors should be used for secondary sampling. Sandvik Mining and Construction (2008) has developed and patented such a unit, the RotaPort™ cone splitter that is functional in wet and dry conditions. Material that hinders sub-sampling should be collected per increment via the cyclone and sun-dried before splitting by means of a riffle splitter.

- QAQC. CRM and blanks should be inserted in batches of samples at a rate of not less than 5%. The expected grade range should be covered by the CRM as well as the 85th percentile of historic values and the cut-off grade.

Underground Grade Control Sampling

The INE, IDE, IEE and IPE have maximum potential influences on underground grade control sampling. The harsh environmental conditions underground, e.g. confined space, heat and humidity make it very difficult for the sampler to define and extract a proper sample. The samples are collected from the advancing face which is at a distance farthest away from the shaft. The heat and humidity contributes to the exhaustion of the sampler. On arrival at the area to be sampled, the sampler has to ensure that the work area is safe from possible falling rocks and methane. The samples to be chipped out from the solid rock are measured at specified intervals and marked on the face. It is a laborious process to chip an exact rectangular from the rock and to collect all the fragments. Recent studies have shown once again that either incomplete or over-chipped samples are collected. The INE is aggravated as the gold grain might be part of either of the two scenarios leading to an incorrect estimation. One mine sub-samples the primary chip samples using a riffle splitter. The potential influence of the IPE was rated as high. The vast number of samples that have to be processed using only one splitter results in careless operation, e.g. passing the sample directly from the bag to the splitter, spillage and discarding of rock chips that do not pass through the vane openings.

An awareness of the TOS and grade discrepancies that exist between the shaft and the plant initiated many projects to find ways of eliminating all sources of bias that contribute to the IDE, IEE, IPE and IWE. Unfortunately the final solution has not been found yet as all the environmental and health and safety requirements could not be satisfied. Hence, it is concluded that:

- The Anglogold Ashanti standard for underground chip sampling that was compiled by Kelly (2006) and revised by Flitton (2009) contains the basic principles as described by Sichel (1947), Storrar (1987) and Cawood (2003) and should be used as guideline for sampling. The requirements for good sampling practice were listed under the following headings:

    - Sample area to be thoroughly clean. This calls for all loose pieces of rock to be removed from the sampling area. Fines and mud should be washed away with clean water.

    - Segregation of reef and demarcation of sample areas. It requires that the reef must be separated according to its apparent quality and geological differences. Sample widths should not be less than 5cm on thin carbon reefs and 7cm on conglomerates but less than 20cm. A waterproof crayon should be used and sharpened frequently so that all lines are thin and clear. Each pair of lines delimiting the width and length of a sample must be parallel and drawn using a clino rule. The lines demarcating the width of the sample are drawn parallel to the reef waste contact while those demarcating the length of the sample are drawn at right angles to the reef waste contact and should be marked out 10cm apart. The sample width should include 2cm of waste rock on either side of the reef band to ensure that the full width of the reef is chipped and any enrichment on the reef waste contacts are included in the sample.

- Measurement of sample widths. This entails the diligent measurement of sample widths to ensure an accurate gold value calculation in cm.g/t. The width of a reef is the shortest distance between the waste rocks on each side, i.e. at a right angle to the reef band.

- Chipping of samples. This prescribes the actual sample collection. The demarcated area must be chipped to a uniform depth of 2cm. The moil should be sharp to ensure cutting of the rock and to prevent "powdering" by means of a blunt edge. The sample dish should be held immediately below the sample being chipped. The cutting edge of the moil should be covered while chipping is in progress to ensure that the rock chips are directed into the dish. All equipment should be cleaned after each sample taken to prevent cross contamination.

- Delivery of samples. Once chipping of the sample is completed it should be meticulously transferred to the sample bag to eliminate loss and contamination. Sample bags must be securely packed for transport from the working place and eventually to surface.

Poor sampling practices were also discussed, e.g. contamination, sample loss and fraud. The document details the stope and face sampling procedure.

- The operators should be motivated, trained and encouraged to maintain a high standard in sampling practice.

- CRM and blanks should be inserted in batches of samples at a rate of not less than 5%. The expected grade range should be covered by the CRM as well as the 85th percentile of historic values and the cut-off grade.

4.3 Broken Ore Sampling

The broken ore from the mining operations is sampled en route to the metallurgical plant. Several sampling methods are active in the Mining Industry:

- Grab sampling from a stockpile or a conveyor
- Stop-belt sampling using a frame
- Go-belt sampling by means of a cross-stream cutter or hammer sampler

4.3.1 Literature

Storrar (1987) refers to Chelius (1973) who reported that a reliable broken ore sampling method was developed that partially or completely replaced chip sampling of the stope faces in the Rand Mines group. He describes the sampling method which does not conform to the requirements for correct sampling as recognised by the TOS. He states that the accuracy of a sample mean only depends upon the number of samples taken and is independent of the tonnage being sampled. He says that a number of samples are collected from the work places during the irregular visits. He also discusses the use of correction factors because the standard broken ore sample procedure calls for the removal of all material with a diameter in excess of 10cm, from the sample. The requirements for correct sampling and sampling frequency will be discussed in detail in this section.

Holmes (2009) discusses the importance of sampling in grade control and lists two requirements:

- The samples should be free of significant bias.
- The precision of the analysis should complement the level of grade control.

He says that sampling systems often do not conform to the requirements for correct sampling (as per definition in 2.3) e.g. samples taken from the side of a stockpile or the top of a conveyor. Coarse particles tend to roll down the side of a stockpile and samples taken from the side will be biased towards the coarse fraction. These samples will not be representative of the ore inside the stockpile. Holmes (2009) states that segregation of ore occurs in all directions on conveyors due to the way the material is transferred from the chute onto the belt and the movement of the idlers. A sample collected from the top or side of the conveyor will inevitably be biased.

Robinson (2008) quotes Gy (1982) on sample correctness when he lists acceptable sampling methods:

- Stop-belt sampling, i.e. manual sampling from a belt using a rigid frame to delimit the sample. Complete extraction should then be executed by removing all the particles including the fines.

- Falling-stream cutter, i.e. a collector that moves across the entire stream at a speed not exceeding 0.6m/s; the collector opening is at least three times the nominal top size of the particles and not less than 10mm; the collector opening has parallel sides and moves at a constant linear speed or has a radial opening and moves a constant angular velocity.

- Discrete portions selection from a stream.

- Sampling when the entire lot is processed.

Robinson et al (2008) used discrete element modelling to investigate sampling mechanisms and concluded that cross-belt sample cutters have a tendency to over-sample parts of the stream and the bias of such unequal representation is estimated at 10%.

Holmes (2009) states that sample loss, contamination, IDE, IEE and preferential exclusion of size fractions are sources of bias that can be eliminated. He reiterates Robinson (2008) statement on best sampling methods of a moving stream, i.e. to collect an increment at a transfer point by means of a complete intersection of the stream at regular intervals. Holmes (2009) lists the criteria for sample collectors to eliminate IDE and IEE:

- The collector should move through the stream at a constant speed, collecting a complete cross-section of the stream and stop away from the stream.

- The complete increment should be discharged and no material should remain in the collector. The collector should be self-cleaning.

- The collector opening should be parallel or radial for linear or Vezin type collectors respectively and intersect the stream at a right angle to the mean trajectory of the stream.

- The collector opening should be at least three times the nominal top size of the particles and not less than 1cm for slurries and fine dry solids and a minimum of 5cm for wet solids.

- The speed of the collector should not exceed 0.6m/s for a cutter opening of three times the nominal top size. The speed can be increased to a maximum of 1.2m/s if the collector opening is also increased.

- The capacity of the collector should be sufficient to collect the entire increment at maximum flow rate of the stream.

Holmes (2009) warns of the pitfalls when moving conveyors are sampled e.g. the bias that is introduced when all the fines are not collected from the belt. Pitard (2005) presents a list of factors which includes those listed by Holmes (2009). In addition he explains that the collector aperture must be greater than or equal to three times the top size of the material to be sampled plus one centimeter. He also describes the importance of inspection doors and explains his concepts by means of diagrams. Pitard (2005) specifies a number of critical factors which influences the correctness of sampling when using go-belt samplers:

- A brush should be installed at the back of the collector to ensure that all the fines are swept from the belt and minimise the IEE. In actuality it was found that a rubber lip works even better as no material can get stuck in the fibres of the brush and it is more durable.

- The capacity of the collector should be sufficient to cater for the amount of material on the conveyor. The collector will fill up if the sides of the cutter are too short. This will result in pushing the material from the belt instead of a scooping the increment.

- There is usually a gap between the edges of the collector and the belt to prevent the cutter from slicing the belt. This design enhances the IDE and results in poor extraction of the increment.

- The rotating velocity of the go-belt cutter promotes the IEE and IPE as some particles may bounce back onto the belt or away from the sample container.

- A go-belt collector should ignore the angular velocity restriction of 0.45m/s and cut through the material at a high speed. The motor should be powerful enough to ensure a constant speed while the collector cuts through the material.

François-Bongarçon and Multotec have developed the Tru-Belt® sampler, i.e. a dry belt sampler that assures sampling theory compliance (Multotec, 2012). The design of the sampler is based on existing go-belt technology, but guarantees the structural absence and near elimination of sample bias. The material is sampled only after it has been removed from the belt. It gives every fragment originally on the belt, the same probability of final selection into the sample (François-Bongarçon, 2011). The sampler has not been seen in operation and an article on the work will be presented at Sampling 2012 in Perth as discussed with Steinhaus (2012) of Multotec Process Equipment, Johannesburg, South Africa.

4.3.2 Guideline

Broken ore sampling is the action of removing an appropriately sized fraction of a bulk amount of broken ore in such a way that the sample is representative of the bulk for the physical properties of interest.

Primary Sampling

Stop-belt sampling consists of stopping the run-of-mine (ROM) conveyor and collecting all the material within a former, of correct dimensions, that is placed on the belt. The method of sampling is recognised by certain international standards as a reference sampling method to determine bias in automatic samplers (Gy, 1982). A stop-belt sampler is an immediate alternative to a costly go-belt sampler. The stop-belt sampler is an inexpensive tool to:

- Test the variability of the plant feed material.
- Ensure correct sampling during an ore campaign.
- Provide sampling frequency information to be used when go-belt samplers are installed.

Pictures of different stop-belt sampler designs are shown in Figure 4.25. The width of the frame should be not less than three times the top size of the crusher product fed to the plant. The blades should follow the curve of the conveyor over the length of the frame i.e. the width of the conveyor.

Figure 4.25 Stop-belt samplers

An example of a go-belt sampler can be seen in Figure 4.26.

Figure 4.26 A go-belt sampler on the left and the collector on the right

Sampling ROM ore with a cross-stream- or go-belt sampler at regular mass intervals eliminates impracticalities like stopping the belt and interrupting the shaft or plant operation. The go-belt sampler, also called a hammer sampler, is a robust instrument and many problems remain unsolved as explained by Pitard (2005). The go-belt sampler operates at a pre-determined frequency. Increments of ROM ore are collected at specific mass intervals. The sampler is initiated when a certain amount of ore passed the weightometer.

At some mines the samplers operate on a time basis. The variance of the IWE is a function of the variation in the flow rate of the stream from which the increments are collected. Therefore the samples should be collected on a mass basis instead of a time interval as the amount of ore on the conveyors varies. Furthermore, the IWE is zero when the increment weight is constant. Some mines have installed profile detectors in the form of laser beams to prevent the sampler from collecting an increment while the profile of the ore on the conveyor is below or in excess of certain predetermined limits.

Rock dump sampling was not investigated as it is usually part of an ad hoc sampling campaign and not included in the metal accounting program. Several stockpile sampling methods are available, e.g. drilling, auger, excavation grab- and belt sampling. Each sampling method has associated problems and therefore grab sampling is usually performed as the inexpensive and easy option. A grab sample from a stockpile gives information just on the sample itself and is unsuitable for any accounting purposes.

Secondary Sampling

Broken ore sample preparation involves sample mass reduction and particle size reduction. However, the splitting at different top sizes, crushing and comminution cannot be done at random. The variance of the FSE, σ_{FE}^2 as identified by Gy (1982) and explained in 2.7.3, is the absolute minimum of sampling errors. Reduction of FSE is achieved by decreasing the diameter of the largest particles or by increasing the mass of the sample. The variance associated with the FSE can be calculated and therefore the appropriate mass of the sample required. Minnitt et al (2007b) describes the 32-piece sampling tree experiment and how to determine a sampling protocol that will ensure that the FSE does not exceed a predetermined precision at any stage in the sampling procedure.

Weightometer

A weightometer is a mass meter or weighing instrument that is installed beneath a conveyor for the purpose of continuous mass determination. It measures the amount of ore on the conveyor passing a certain idler or number of idlers included in a weigh frame. In general, the more idlers on a weigh frame the less the effect of belt tension and alignment and the longer the instrument will remain in calibration. Figure 4.27 shows a single idler weightometer, i.e. one row comprising of three idlers on a weigh frame. The tachometer which measures the speed of the conveyor is shown in the picture on the right. Together these instruments provide the data for the mass per time calculation, i.e. mass flow measurement.

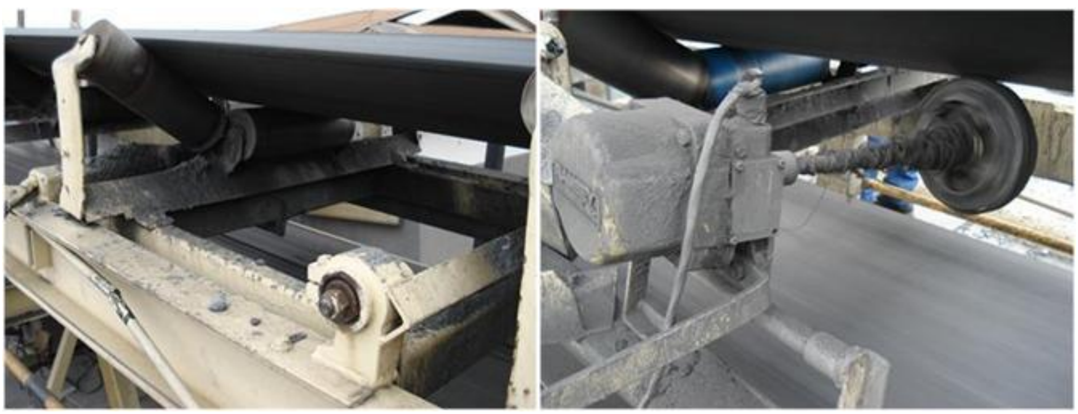

Figure 4.27 A single-idler weightometer on the left and a tachometer on the right

It is imperative that the calibration of the weightometer should be checked weekly using a static weight, e.g. the calibration chain pictured in Figure 4.28. A full calibration can then be completed if the check shows that a bias exists.

Figure 4.28 Calibration chain of a plant feed weightometer

Sampling Frequency

Samples should be collected on a mass basis (and not a time interval) to provide for fluctuating mass loads on the conveyor. A link via the process control computer between the weightometer and sampler can be used to enable sampling per mass interval.

The sampling frequency can be determined by using a stop-belt sampler. This can be done during the planning phase before installing a go-belt sampler. The following procedure should be followed for every ore source to determine the minimum sampling frequency required:

- A stop belt sampling exercise should be carried out when unblended ore from a specific source is fed to the plant. The conveyor should be stopped after 250 tonnes have passed the weightometer, the frame lowered onto the belt and all the ore between the blades should be transferred to a sample container. If more than one container is used per sample, it should be labelled accordingly to represent one sample only. Care should be taken to ensure that all fines are collected in the sample and a brush should be used to clean the belt. The interval of 250 tonnes is chosen arbitrarily and will be fine-tuned later on in the procedure.

- Each sample should be treated individually in the laboratory and the appropriate procedure should be followed to clean the equipment between samples. The samples should be dried before crushing. Each complete sample should be crushed.

- Each complete sample should be submitted to the primary splitter before a sub-sample may be removed for milling. The same splitting process should be followed for each and every sample.

- Each sample should be assayed in duplicate and suspicious values should be confirmed by a repeat in duplicate. All values should be reported.

- The sampling error variance should be calculated and the sampling frequency should be determined according to Spangenberg (2007). It should be noted that the calculated sampling frequency will only be applicable to the specific ore source.

- The sampling frequency should be refined to cater for the mixed ore feed after the commissioning of a go-belt sampler.

The semi-variogram procedure (Gy, 1982) should be used to quantify segregation and determine the optimum go-belt sampling frequency. An expert will need to define the standard in the case where no structure is evident in the variogram. The classical statistical approach should be used to determine the standard error of the mean as a variance:

Error variance = Variance / Number of samples

where

Variance = $(\text{Relative standard deviation})^2$

and

Relative standard deviation = Standard deviation / Average grade

In certain cases this formula cannot be used and the error variance should be calculated using the geostatistical approach, i.e. Kriging. The sampling frequency should not be less than the minimum rate as determined by the procedure. If samples are taken at a higher frequency, it will benefit the final sample representation but it might overload the sample preparation facility.

Sampling Precision

The following procedure should be followed for every ore source to determine the sampling precision and protocol. The sampling protocol is an important first step in the design of a broken ore sample preparation (BOSP) facility.

- A 30kg sun-dried sample of every major ore source should be collected. The sample fragments may be collected by hand. The total sample may consist of one rock only. The fragments should be carefully selected to ensure that the sample is representative of a specific ore type.

- The sample preparation protocol for every ore type should be determined using Gy’s model as modified by François-Bongarçon (Minnitt et al, 2007b). Please refer to Nomograms in 4.3.3 for sampling precision test work.

Individual and Composite Samples

A sampler should take as many increments as practically possible as explained in 2.7.4. The mass of the composite sample should be controlled to maintain the variance below the level considered acceptable. The sample mass required should be determined by constructing a nomogram for the specific ore. Mined ore are usually transferred via grizzlies onto conveyors. The purpose of the grizzly is to limit the top size of the rocks so that the ore can pass easily through all the chutes. It may be impractical to collect a composite broken ore sample at a top size of 30cm, i.e. the grizzly aperture generally encountered, as the final sample mass might consist of several tonnes. The minimum cutter width is 90cm when the nominal top size D_{95} is 30cm, i.e. 95% of the material will pass through a screen aperture of 30cm.

4.3.3 Observations

Table 4.4 lists the elements of broken ore plant feed sampling that were rated. The spread sheet provided for information to be recorded on whether individual or composite samples are collected, the number of idlers on the weightometer and the status of the weightometer in the metal accounting system.

Table 4.4 Summary of the average potential influence of specific sampling errors on elements of broken ore sampling

		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									Average Potential Influence			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
2	**MINING**													
2.3	**Broken ore plant feed sampling**													
	Stop-belt		3.0	5.0	5.0	5.0	5.0	5.0	3.0		4.4	5.0	88.6	High
	Go-belt		3.0	5.0	4.6	5.0	5.0	4.8	3.6		4.4	5.0	88.8	High
	Cross-stream													
	Other : grab		4.6	5.0	5.0	5.0	5.0	5.0	5.0		4.9	5.0	98.9	High
	Average for section in %		70.7	100.0	97.4	100.0	100.0	99.0	77.4				**92.1**	**High**

Note : An empty cell indicates that the element of sampling was not encountered.
Potential influence of sampling error is low = 1, medium = 3 or high = 5.
(0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high

At the open pit mines it was found that ore is usually delivered from the mining areas to several stockpiles according to the source and estimated grade. Ore from different stockpiles outside the plant are blended on a pad and transferred to a crusher. The crushed material flows via a series of screens and a secondary crusher to the plant stockpile. A weightometer measures the plant feed mass flow to the plant stockpile.

It was observed at one of the mines that grab samples are collected from the pad. The evaluation department uses this sampling method when they have to estimate the plant feed grade for planning purposes. It was noticed that all fragments selected for each sample are less than 10cm in diameter as that is the top size that can be processed by the primary crusher at the BOSP facility. No fines are selected when the samples are collected as the rocks are hand-picked. These samples are biased and the values cannot be used to dispute the plant head grade.

Plant Feed Sampling

Composite samples are collected on a time basis by 29% of the mines. The sampling frequency is usually restricted to reduce the mass of the composite sample that is collected per shift. None of these mines determined the final sample mass by means of a nomogram. Neither the variographic nor statistical method was used to calculate the desired sampling frequency. It is evident that these mines modified the sampling procedure for logistical purposes and not to enhance sampling precision.

Individual increments are collected by 57% of the mines. The values of the individual samples can be used in the sampling frequency calculation. Individual samples can be easier handled, dried and prepared than composite samples. The mass of the sample per increment is site dependant. The profile of the material on the conveyor and set parameters, e.g. belt width and blade width define the sample mass.

The status of the weightometer in the metal accounting system was recorded on the spread sheet. The flow meter and densitometer in the metallurgical plant usually form the centre of mass measurement in the metal accounting system as these instruments have a smaller margin of error than a weightometer. Nevertheless, it was found that two mines use a single-idler and two-idler weightometer respectively as primary mass flow meters. Only six-idler weightometers are considered sufficiently accurate for metal accounting purposes.

Table 4.4 is a summary of the average potential influence of the relevant sampling errors on elements of broken ore sampling. It was found that 10% of the mines do not collect any plant feed samples and 24% of the operations perform grab sampling. The potential influence of all the sampling errors namely FSE, GSE, IDE, IEE, IPE, PIE and IWE was rated as high at these particular operations. The remainder of the mines use stop- or go-belt samplers and the same sampling errors are encountered with a total influence that was rated as high.

Figure 4.29 shows how broken ore on a moving conveyor is grab sampled by means of a spade. The specimen is collected from the top of the material on the conveyor. The sample is incorrect as per definition in 2.3 and hence called a specimen. Broken rock on a conveyor is always segregated. The particles at the bottom of the profile have no probability of being selected in the sample. Larger particles similar to the rock on the right hand side of the picture will also never be collected from the moving conveyor. In this case the potential influence of the IDE is high as the increment to be extracted is not a cross section of the material on the conveyor and not of appropriate dimensions, i.e. three times the nominal top size, D_{95} of the material.

The potential influence of the IEE is high as the collector of the sampler is designed incorrectly and can never extract a correct sample. The potential influence of the IWE and PIE are also high as the sampling is not proportional and the sampling frequency was set to satisfy logistical requirements. It is evident that all the sampling errors as named above have a large potential contribution to the TSE.

Figure 4.29 Broken ore on a moving conveyor is grab sampled by means of a spade

Stop- and go-belt samplers have inherent problems that contribute to the TSE. The dimensions of the sampler may be incorrect. The blades should be at least three times the top size, D_{95} of the material, apart. The blades should also follow the curve of the conveyor so that a clear cut of the material can be made from the top of the material right down to the bottom where it meets the belt. There should be no doubt whether a particle should be included in the sample. The sample should be collected meticulously to ensure that all the fines are collected from the conveyor.

Figure 4.30 shows an example of a go-belt sampler that was designed incorrectly. A number of mechanical deficiencies that contribute to the high potential influence of the IDE, IEE and IWE are:

- The power of the motor is inadequate to drive the collector at a constant speed through the material on the conveyor. The collector stuck in the material when the picture was taken.

- The sides of the collector are not long enough to form a bucket that scoops the material from the conveyor. The collector fills up almost immediately resulting in pushing of the material instead of a scooping action. The material escapes from the sides and an incomplete increment is collected.

- Figure 4.30 displays the material that remained on the conveyor after sampling. The lines indicate the trajectory of the collector. An incomplete sample was collected as most of the fine material remained on the conveyor. This problem, i.e. IEE, can be rectified by installing a rubber lip on the collector and support below the conveyor.

Figure 4.30 Go-belt sampler in operation on the left and material that remained on the conveyor after sampling on the right

The picture on the left in Figure 4.31 reveals that there is no support below the conveyor to assist the collector in taking a clean cut. The picture on the right shows that the sample container is too shallow and part of the sample ejects. The operator transfers the sample from the container into rubber bags.

Figure 4.31 The conveyor bed on the left and the go-belt sample container on the right

The go-belt samples are biased and cannot be called samples; rather specimens. Gold might be concentrated in the fines that remain on the belt, i.e. IEE. These specimens are collected at two-hourly intervals regardless of the mass flow, i.e. IWE. The sampler and container should be modified to ensure that a complete increment is collected. Support underneath the conveyor will assist the cutter in collecting all the material from the belt. An example is presented in Figure 4.32. The support can be a plate and idlers or just idlers. A sample container of adequate size should be used to prevent any sample loss.

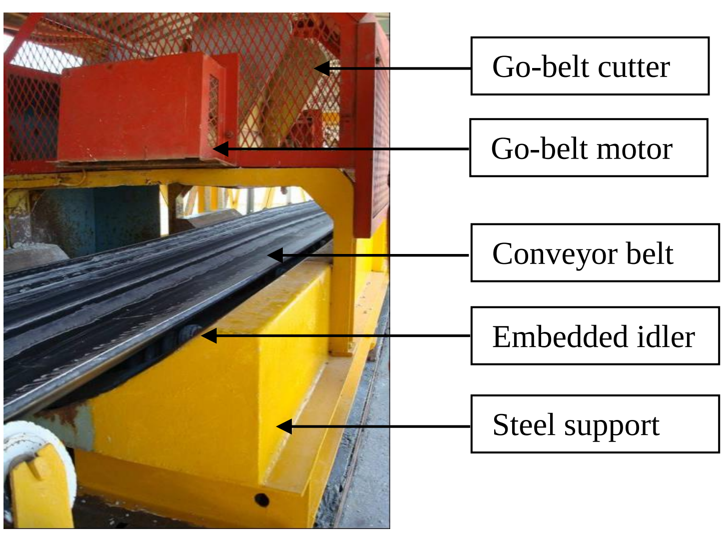

Figure 4.32 Support below conveyor

The average potential influence of the sampling errors was rated as high at 92.1% on elements of broken ore sampling. The potential influence of the specific sampling errors is shown in Figure 4.33.

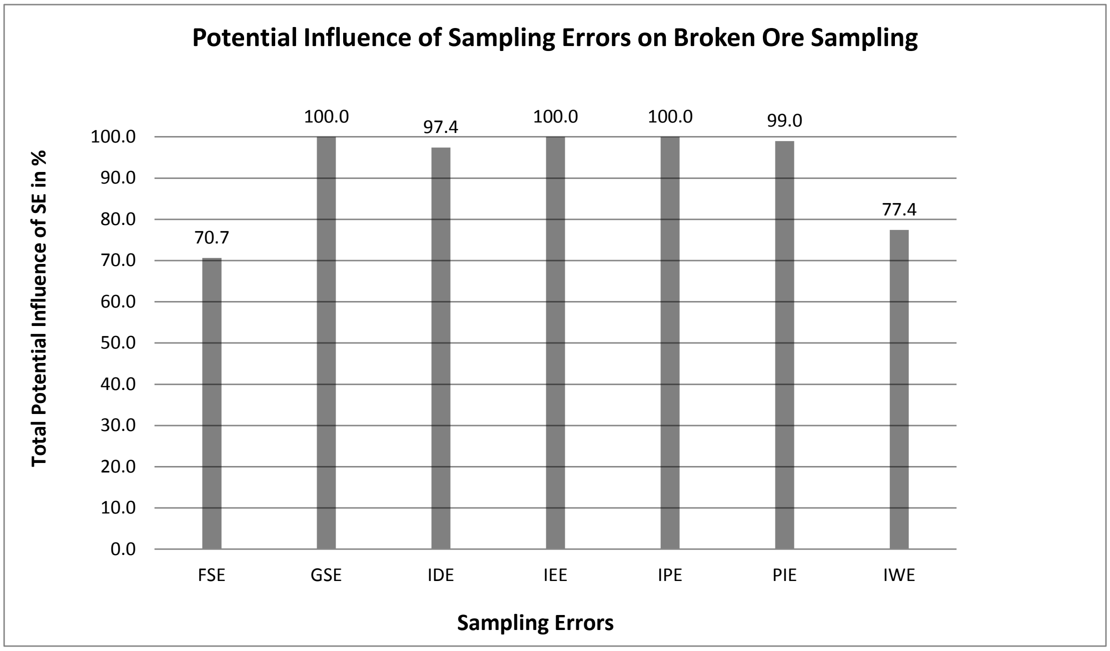

Figure 4.33 Average potential influence of specific sampling errors on elements of broken ore sampling

Broken ore sample preparation

The visits revealed that all the broken ore sample preparation facilities did not receive the capital required to invest in equipment that is adequately sized for the task at hand. At some facilities it was found that ovens, crushers, mills and splitters are timeworn and personnel rely on breakdown maintenance to keep equipment operational. However, some mines did embark on programs to rectify the existing state of affairs. They initialised the upgrading by requesting nomograms to be constructed to establish a sampling protocol and design of a proper preparation facility. New equipment, e.g. crushers and rotary splitters were procured to cater for the increase in sample quantities.

At one facility it was found that the content of the sample container is spread out on a rubber mat. The large particles are selected by hand and then transported to the primary crusher by wheelbarrow as shown in Figure 4.34.

Figure 4.34 Sample preparation process

The top size of the primary crusher product is ±10cm. The moist material is not dried before crushing. The crusher is a source of cross contamination as it is cleaned by brush only. The picture on the far right shows the fines left behind in the feed chute of the crusher.

The smaller particles and primary crusher product are submitted to the secondary crusher displayed in Figure 4.35. The secondary crusher produces a top size of ±2.5cm. The crusher is cleaned by brush and compressed air.

Figure 4.35 Sample preparation equipment

The Laboratory Guideline (Maree, 2007) has the following on cleaning of equipment: Best practice: The crusher should be flushed with minimum 200g inert silica rock chip material (25mm to 50mm) to remove any sample remaining in the crusher before crushing the next sample. This should be done to prevent contamination between samples. At least one crusher blank sample (flushing material after the crusher has been cleaned) associated with each feed source should be assayed for gold each day.

Acceptable practice: The crusher should be cleaned before and after the processing of each source with 200g inert silica rock chip material (25mm to 50mm). The crushed material, crusher blank sample (flushing material without flushing the crusher) associated with each feed source should be assayed to determine the gold content every day. The flushing, only between feed sources, will be acceptable if the gold value of the crusher blank is less than 0.3g/t.

The primary splitter is a multi-stage riffler that produces 1/8 sub-samples. The picture in the middle of Figure 4.35 reveals that the sample is transferred to the splitter by means of a spade instead of a feeding pan. Particles that cannot pass through the vanes are merely discarded. Residual material is evident in the picture on the right. This is a source of cross-contamination. The splitter is biased by design as sub-samples are always transferred from the same side to the next splitting stage, i.e. preferential sampling. The secondary splitter is a new six-way cascade rotary splitter as shown in Figure 4.36. One increment is submitted for assay.

Figure 4.36 A six-way cascade rotary splitter

In this case the sampling precision cannot be calculated since the crushing and splitting processes are varied from one sample to the next e.g. a sample will be riffle split until the mass is reduced to less than 10kg for secondary crushing. The sample preparation process is labour intensive and the equipment is not user-friendly. Opportunities for cross contamination exist as the material is not dried before crushing and waste rock is not used to clean the crushers between samples.

Nomograms

A number of the mines requested assistance on the design and optimisation of broken ore sampling facilities. Three mines are planning the design and installation of new samplers and preparation facilities. Eight nomograms have been completed for these mines to address all the reef types. Several mines endeavour to optimise their existing equipment and procedures. Four nomograms were constructed for these mines. The assistance comprised of the experimental procedure proposed by François-Bongarçon (1995) to establish the sampling parameters for a type of reef at a specific average grade. These parameters can then be used to get a better understanding of the variance of the FSE. The result can be applied in the construction of a sampling nomogram.

The nomogram is indispensable when a new sampling protocol has to be established for the design of a preparation facility. The designer can use the nomogram to ensure that the variance of the FSE does not exceed a predetermined precision at any stage of the sampling procedure. The sample preparation equipment, i.e. crushers, splitters and pulverisers can then be selected accordingly.

The nomogram can also be used as a means to optimise the protocol at an existing facility once the fundamental error variance has been determined. It can then be decided whether some or all of the equipment should be replaced. Alternatively, the error variance can be minimised by adjusting the protocol, e.g. the collection of different fractions during mass reduction steps.

An example of nomogram test work that was completed is discussed in 4.2.3 to illustrate the application in the two scenarios, i.e. new design of protocol and optimisation of existing protocol. The experimental procedure was described in detail by Minnitt et al (2007b) and only the results are presented. Table 4.13 is a summary of the liberation size, K- and α-values that were determined.

Current sampling protocol

The experimental procedure as described by Minnitt et al (2007b) was followed to determine the sampling precision of an existing sampling and preparation installation at the mine. Once the sampling parameters were calibrated, the information could be used to suggest an alternative sampling protocol for the existing equipment to improve the sampling precision.

Four size fractions were used, i.e. 95% passing 19mm, 12mm, 4.75mm and 1.18mm. The assay values of the four groups at different nominal sizes are listed in Table 4.5. These values were used to calculate the statistical and other data shown in Table 4.6. Figure 4.37 displays some of the equipment that were used in the crushing, splitting, sifting and milling process.

Figure 4.37 From left to right: crusher, riffler, mechanical sieve and mill bowl

Table 4.5 Assay values of the groups at different nominal sizes

Sample number	Group 1 Au in g/t	Group 2 Au in g/t	Group 3 Au in g/t	Group 4 Au in g/t
1	6.75	4.67	8.83	8.35
2	13.40	6.86	9.17	8.37
3	6.97	9.46	10.80	9.46
4	8.29	10.20	8.81	8.94
5	9.26	8.16	7.16	8.01
6	8.04	7.18	7.63	7.84
7	6.80	7.17	8.42	8.58
8	14.40	9.83	10.20	8.65
9	9.76	8.95	8.12	8.75
10	9.30	6.85	9.70	9.00
11	11.40	9.73	10.10	8.29
12	4.33	6.18	11.30	8.88
13	19.90	5.92	9.30	9.11
14	5.80	12.30	7.85	9.08
15	4.65	6.85	8.47	9.86
16	7.12	16.90	8.37	7.88
17	5.63	6.35	7.45	8.20
18	10.10	7.30	8.73	7.91
19	9.73	13.10	8.15	9.86
20	6.50	6.28	7.70	8.78
21	9.78	7.34	9.09	8.97
22	6.55	7.32	8.24	7.67
23	9.67	11.80	7.73	8.48
24	8.47	8.49	9.54	9.16
25	11.20	8.18	7.57	9.82
26	16.70	7.24	9.46	8.45
27	5.45	5.07	9.48	7.48
28	5.68	7.46	11.60	8.31
29	8.25	6.85	7.14	8.17
30	6.38	8.52	9.69	9.40

Table 4.6 Statistical data and data required to construct the graph

Description	Symbol	Unit	Groups			
			1	2	3	4
Sample mass	M_S	g	276	192	266	233
Nominal size	d_n	cm	1.9000	1.2000	0.4750	0.1180
Mean of grade		g/t	8.88	8.28	8.86	8.66
Maximum grade		g/t	19.90	16.90	11.60	9.86
Minimum grade		g/t	4.33	4.67	7.14	7.48
Standard deviation	s		3.49	2.53	1.16	0.63
Variance	v		12.17	6.41	1.34	0.40
Relative standard deviation	σ		0.3931	0.3057	0.1307	0.0731
Relative variance	σ^2		0.1545	0.0935	0.0171	0.0053
Analytical variance	v_a		0.0016	0.0016	0.0016	0.0016
Relative variance corrected	v_c		0.1529	0.0919	0.0155	0.0037
Standarised variance	σ_c^2		1.3573	0.7610	0.1371	0.0324
$Ln(\sigma_c^2 M_S)$			5.926	4.984	3.596	2.022
$Ln(d_n)$			0.642	0.182	-0.744	-2.137

The numbers in Table 4.6 were used to construct the graph in Figure 4.38.

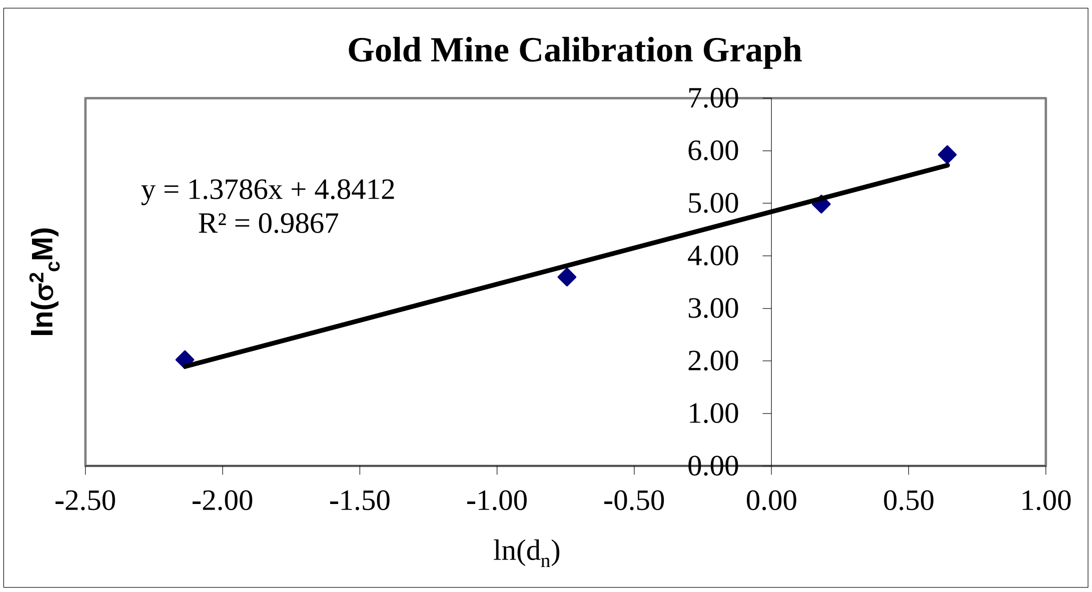

Figure 4.38 Linear graph to calibrate α and K for an average gold grade of 8.7g/t

The correlation coefficient is 99.3%. Alpha and ln(K) were derived from the graph and listed in Table 4.7.

Table 4.7 Parameters from graph

Constant	Value
α	1.38
ln K	4.84
K	126.62

The current sampling technique is summarised in Table 4.8 and presented graphically in Figure 4.39.

Table 4.8 Current sampling protocol

Size cm	Mass kg	Rel std dev %	Relative variance	Position
30.0	50.00	52.47	0.2754	A
2.5	50.00	9.46	0.0090	B
2.5	4.17	32.78	0.1075	C
0.6	4.17	12.26	0.0150	D
0.6	0.83	27.41	0.0751	E
0.0075	0.83	1.34	0.0002	F
0.0075	0.05	5.46	0.0030	G

The current sampling protocol consists of the following steps as listed in Table 4.8:

- The go-belt sampler at this mine collects individual increments of ±50kg at a top size, D_{95} of 30cm. The relative variance is plotted at position A in Figure 4.39.

- Each sample is dried in an oven and then crushed. The primary crusher delivers a top size of ±2.5cm. The equipment is not cleaned between samples and carry-over contamination occurs. The crusher should be cleaned by brush, air and inert material after each sample to minimise the variance of the fundamental error. The relative variance is plotted versus the fraction mass at position B.

- The primary cascade rotary splitter comprises of 12 buckets and one sub-sample is retained for the following step. This mass reduction is indicated by position C.

- The sub-sample is crushed by means of a secondary crusher to a top size of ±0.6cm and this size fraction reduction is shown at position D in Figure 4.39.

- The secondary cascade rotary splitter comprises of 10 buckets and two sub-samples are retained for the following step. This mass reduction is indicated by position E. The two sub-samples are combined before it is submitted for milling.

- The sub-samples are milled to a fraction size of 95% passing 75µm and this is pointed out by position F.

- The final aliquot for fire assay is 50g and this is shown by position G.

- The analytical error is an estimated 4%.

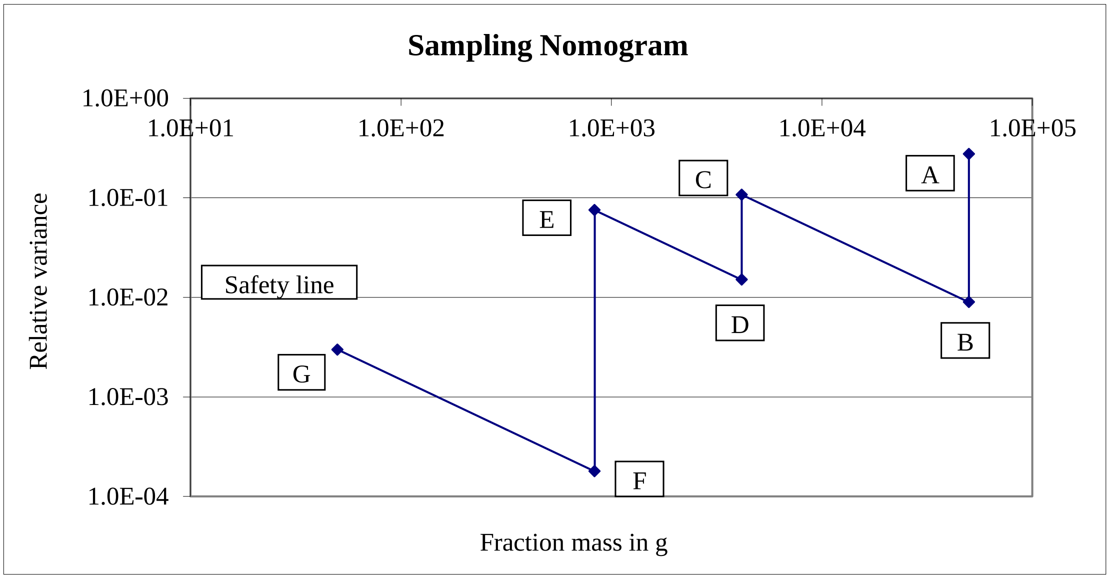

Figure 4.39 Sampling protocol chart for current procedure

It is evident from the nomogram that Gy’s recommended 10% relative error safety line is breached. This means that the precision may be out of control. Table 4.9 put the information derived from the nomogram into perspective at the hand of an example using an average gold grade of 8.0g/t:

Table 4.9 Sampling precision per period

Description			Value	8 samples/shift	24 samples/day	26 days/month
Incremental variance			0.4368	0.0546	0.0182	0.0007
% Relative standard deviation			66.09	23.37	13.49	2.65
<u>Example :</u>						
8.0	g/t	2 x s	10.57	3.74	2.16	0.42
		Lower limit	-2.57	4.26	5.84	7.58
		Upper limit	18.57	11.74	10.16	8.42

- The percentage relative standard deviation, i.e. precision is 66.1% for one sample only. That means that an average gold grade of 8.0g/t may be reported between the two standard deviation limits of zero and 18.6g/t.

- The precision improves to 23.4% when, for example, 8 samples are collected per shift and the average grade of all the samples is calculated. The two standard deviation limits are 4.3g/t and 11.7g/t for an average grade of 8.0g/t. It is apparent that precision is poor and the Process Metallurgist cannot report an acceptable head grade for metal accounting purposes as it can be any number between 4.3g/t and 11.7g/t.

- The precision is an estimated 13.5% when a daily average grade is calculated from 24 sample values and the grade may be reported as 8.0g/t ± 2.2g/t.

- The precision of a monthly average grade of 8.0g/t is 2.7% and two standard deviation limits are 7.6g/t and 8.4g/t when all the values received during the 26 days are used in the calculation.

It should be noted that the sampling frequency of 8 samples per shift is for explanatory purposes only. The actual sampling frequency should be determined as described in 4.3.2.

Table 4.10 is a summary of the statistics used to calculate the liberation size. The size compares well with known mineralogical characteristics of the ore.

Table 4.10 Statistics for ore with an average grade of 8.7g/t

Description	Symbol	Unit	Groups			
			1	2	3	4
Sampling constant	K	g/cm$^{\alpha}$	126.62	126.62	126.62	126.62
Slope of calibration curve	α		1.38	1.38	1.38	1.38
Density of gold-alloy	ρ	g/cc	16.00	16.00	16.00	16.00
Grade		g/t	8.88	8.28	8.86	8.66
Shape factor	f		0.50	0.50	0.50	0.50
Granulometric factor	g		0.25	0.25	0.25	0.25
Liberation size	d_l	μm	98.94	94.81	98.83	97.43

The mass of sample that should be collected from a pile of ore (D_{95} = 30cm), not to exceed a precision of 10%, is 607kg. The many aspects of correct sampling practice should be applied when such a sample has to be collected.

Alternative sampling protocol

The calibrated sampling parameters were applied to construct a nomogram while bearing the safety line in mind. The purpose of the alternative sampling protocol was to reduce the incremental variance and hence to improve the sampling precision. The optional sampling protocol had to utilise the existing equipment to eliminate possible capital expenditure. The proposed sampling technique is summarised in Table 4.11 and presented graphically in Figure 4.40.

Table 4.11 Suggested sampling protocol

Size cm	Mass kg	Rel std dev %	Relative variance	Position
30.0	200.00	26.24	0.0688	A
2.5	200.00	4.73	0.0022	B
2.5	50.00	9.46	0.0090	C
0.6	50.00	3.54	0.0013	D
0.6	6.25	10.01	0.0100	E
0.0075	6.25	0.49	0.0000	F
0.0075	0.05	5.46	0.0030	G

The alternative sampling protocol consists of the following steps as listed in Table 4.11:

- The go-belt sampler collects four increments of ±50kg at a top size, D_{95} of 30cm and combine. The relative variance is plotted at position A in Figure 4.40.

- Each 400kg sample is dried before crushing. The primary crusher delivers a top size of ±2.5cm. The relative variance is plotted versus the fraction mass at position B.

- The primary cascade rotary splitter comprises of 12 buckets. The contents of three containers are combined for the following step. This mass reduction is indicated by position C.

- The sub-sample is crushed by means of the secondary crusher to a top size of ±0.6cm and this size fraction reduction is shown at position D.

- It is suggested that the 10-way secondary cascade rotary splitter should be replaced by an 8-way splitter which is readily available on site. This mass reduction is indicated by position E. One sub-sample is submitted for milling.

- The product of the mill is 95% passing 75µm and this is pointed out by position F in Figure 4.40.

- The final aliquot for fire assay is 50g and this is shown by position G.

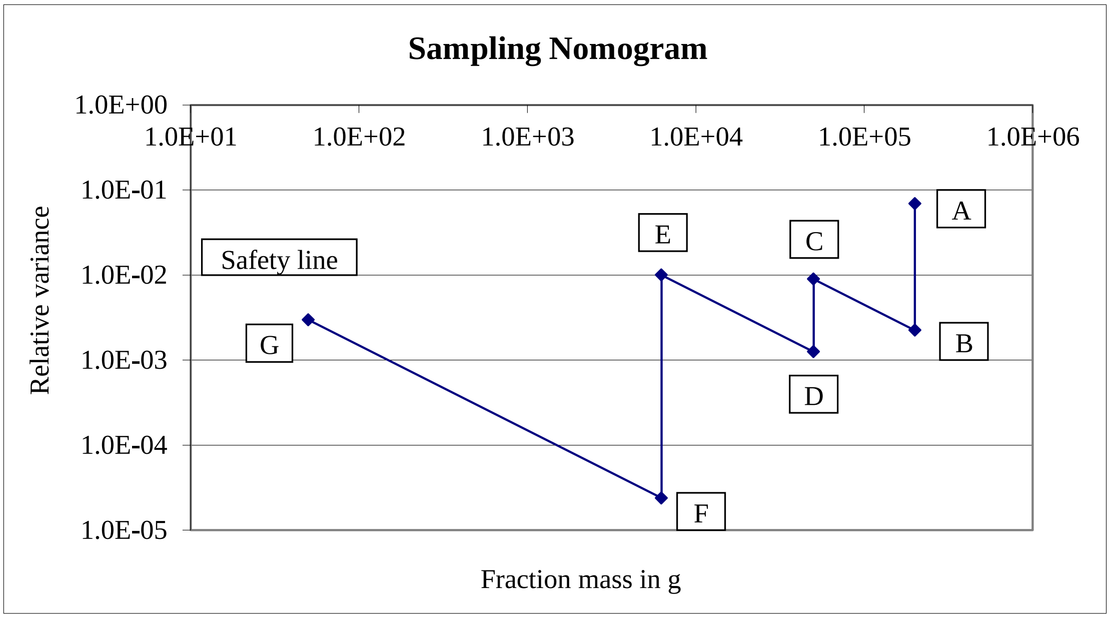

Figure 4.40 Sampling protocol chart for alternative procedure

The precision of the first step is greater than 10% as the initial sample mass had to be kept within practical and logistical limits. All the other steps of the suggested procedure were below the safety line. Table 4.12 illustrates the information derived from the nomogram using an average gold grade of 8.0g/t as an example:

- It is evident that the precision improved dramatically. The daily grade can be reported with a two standard deviation range of 0.96g/t, i.e. 8.0g/t ± 0.96g/t.

- The precision of a monthly average grade of 8.0g/t is 1.2% and two standard deviation limits are 7.8g/t and 8.2g/t when all the values received during the 26 days are used in the calculation.

Table 4.12 Sampling precision per period for alternative protocol

Description			Value	8 samples/shift	24 samples/day	26 days/month
Incremental variance			0.0873	0.0109	0.0036	0.0001
% Relative standard deviation			29.54	10.44	6.03	1.18
Sampling representation in % on 95% confidence level			57.90	20.47	11.82	2.32
Example :						
8.0	g/t	2 x s	4.73	1.67	0.96	0.19
		Lower limit	3.27	6.33	7.04	7.81
		Upper limit	12.73	9.67	8.96	8.19

Summary

The nomogram is essential when a sampling protocol has to be established for the design of a sample preparation facility. Equipment can then be installed to honour the requirements of the protocol.

The nomogram can also be used as a means to optimise the protocol at an existing facility once the sampling parameters have been calibrated and the fundamental error variance has been determined. It can then be decided whether some or all of the equipment should be replaced. Alternatively, the error variance can be minimised by modifying the protocol, e.g. different portions during mass reduction steps.

General

Table 4.13 is a summary of the liberation size, K- and α-values that were determined for the different ore types. This is of interest to Sampling Specialists. The calculated liberation sizes compares well with dimensions reported by mineralogical studies completed by the mines.

Table 4.13 Summary of sample parameters and liberation size

	Reef from open pit mines						
Parameters	A	B	C	D	E	F	G
K	14.4	11.9	23.3	67.5	162.2	46.3	410.2
α	1.0	0.3	1.0	1.0	0.8	0.6	0.5
d_l	42	241	81	115	105	161	508
Grade (g/t)	2.4	7.9	4.9	4.5	0.5	2.2	3.2
	Reef from underground mines						
	A	B	C	D	E	F	
K	36.3	86.7	126.6	97.0	73.0	54.1	
α	0.4	0.7	1.4	0.6	0.6	0.5	
d_l	232	290	97	109	139	103	
Grade (g/t)	3.2	7.5	8.7	5.7	9.6	8.0	

François-Bongarçon (1993) reported values for α in the range of 1.5 and Assibey-Bonsu (1996) listed values between 0.76 and 1.15. Afewu and Lewis (1998) reported an α-value of 1.01 for low-grade ore (± 5g/t) and 1.13 for high-grade ore (± 60g/t).

4.3.4 Conclusions

The GSE, IDE, IEE, IPE and PIE have maximum potential influences on broken ore sampling. It remains problematic to sample broken rock at a top size of 30cm from a moving conveyor. The fines accumulate at the bottom of the segregated profile and it is rarely entirely collected; hence the GSE. Broken ore is not sampled by means of a correctly designed cutter width of three times the top size as this will produce large sample masses. The collectors usually have a blade width of 50cm and therefore the influence of the IDE. The mechanical action of the go-belt sampler is of such a nature that a complete sample is hardly ever collected from a conveyor. Fines remain on the belt whether the sample is collected by the hammer sampler or the operator performing stop-belt sampling. Production time is of the essence and therefore the operator will endeavour to collect the sample as quickly as possible to minimise the interruption. These are contributing factors to the IEE. There is awareness by mine managers of the fact that nomograms exist and that it can be used to explain some of the differences between the mine sample grade and the plant head grade. The grade interval for the values reported can be calculated once the fundamental error variance has been determined as shown in Tables 4.9 and 4.12.

It is concluded that the acceptable standard should be set according to the requirements for broken ore sampling as described by Pitard (2005), Spangenberg (2007), Robinson (2008) and Holmes (2009):

- Weightometer. Only six-idler weightometers are considered sufficiently accurate for metal accounting purposes. The calibration should be checked weekly by carrying out a zero test, i.e. unloaded running conveyor and static weight test, i.e. running conveyor loaded with measured mass pieces or a calibrated chain.

- Sampler. The collector opening should be at least three times the nominal top size of the particles and not less than 10mm for fine dry solids and a minimum of 50mm for wet solids. The capacity of the collector should be sufficient to cater for the amount of material on the conveyor. A rubber lip must be installed on the cutter edge of a hammer sampler to ensure a clean sweep of the belt. Support below the conveyor can assist the cutter in collecting all the fines from the belt. The collector opening should be parallel or radial for linear or Vezin type collectors respectively and intersect the stream at a right angle to the mean trajectory of the stream.

- Sampler operation. Sample collection should be initiated when a pre-determined amount of ore passed the weightometer. The collector should move through the stream at a constant speed, collecting a complete cross-section of the stream and stop away from the stream. The complete increment should be discharged and no material should remain in the collector. The collector should be self-cleaning. A go-belt collector should cut through the material at a high speed. The motor should be powerful enough to ensure a constant speed while the collector cuts through the material.

- Detector. A detector should be installed to stop the belt when a large rock is detected. Oversize material should be removed from the conveyor to prevent chokes and damage to the sample collector and belt. Broken rocks should be loaded before the sampler to give it an opportunity to be sampled.

- Safety. The sampler should be enclosed to prevent injury from flying rock chips. Inspection doors should be available for access to all parts of the sampler.

4.4 Metallurgical Plant Sampling

This section includes head-, residue- and bullion sampling. The broken ore is milled and the slurry is sampled after thickening en route to the leaching area. The final residue and bullion are sampled to calculate the total amount of gold produced by the metallurgical plant. The slurry is usually sampled by means of:

- Grab sampling
- Cross-stream launder samplers
- In-line cross stream samplers
- Injector samplers which is also called poppit samplers
- In-line pipe diversions and probes

Dip- and drill sampling are two methods used to sample bullion.

4.4.1 Literature

François-Bongarçon (2002) explained that samplers should conform to the third mode of sampling to be correct (as described in 2.4). Only cross-stream samplers that collect increments of the complete stream fall into this category. Bartlett and Hawkins

(1987) say that there are no guarantees that grab samples will be unbiased and add that the precision of this sampling method is sub-standard compared to mechanical samplers. They present a diagram of a sample cutter for pulps and list a number of requirements:

- The collector parks away from the process stream.
- The collector activates on a time basis, i.e. every five minutes or the sampling frequency can be determined by precision experiments.
- The cutter moves across the stream to collect an increment.
- The secondary sampler collects duplicate samples.
- Water sprays cleans the collector when it is in the parked position and the wash water is collected in the sample.

This basic design was modified by Anglogold Ashanti and Multotec who embarked on a program to develop a cross-stream sampler that conforms to the theoretical requirements of a correct sampler (Spangenberg, 2007). The design was endorsed by Dr D François-Bongarçon and has since been installed at 12 of the metallurgical plants visited.

Bartlett and Hawkins (1987) describe the pipe and injector samplers for non-probabilistic sampling. They say that the process stream will be homogeneous if the mixing is good enough and consequently the sample may be collected from any part of the stream. This sampling method belongs to the second mode of sampling as described by François-Bongarçon (2002), i.e. taking part of the flow all of the time and therefore it is incorrect.

Secondary sampling is usually performed by means of rotating Vezin-type samplers. Pitard (2005) stipulated the requirements to ensure sampling correctness at the WCSB2:

- The distance between the stream discharge and the cutter edges should be greater than or equal to three times the nominal top size D_{95} plus 2cm to minimise the IDE.

- The angular speed of the collector, measured at the farthest point from the axis where the stream is cut, should be less than 45cm/s for Vezins with a diameter larger than 60cm and less than 30cm/s for smaller diameter samplers to minimise the IEE.

- The aperture of the collector, measured at the closest point from the axis where the stream is intercepted, should be greater than or equal to three times the nominal top size D_{95} plus 1cm to minimise the IEE.

- The distance between the farthest point from the axis where the stream is cut and the outer end of the collector should be a minimum 5cm to minimise the IEE. The same requirement applies to the distance between the inner end of the collector and the point where the stream is intercepted.

- The cutter edges, also called the blades of the collector, should be radial with respect to the centre of rotation to minimise the IDE.

- The IDE and IEE can be minimised by ensuring that the blades are symmetrical and blunt with a flat area of ±0.75mm. The outer slope of the blades should be at an angle of $\pm 70^{o}$.

- The capacity of the collector and the discharge should be sufficient to cater for the entire cross-cut and to eliminate any overflowing.

- An adequately sized inspection door should allow for unobstructed viewing of the collectors.

Van der Walt (2002) wrote in his comment that dip sampling of molten bullion is an incorrect sampling method. He identified the errant mechanism as a degree of pre-refining taking place through the boiling-off of certain metals and a misrepresentation of slag constituents.

4.4.2 Guideline

Mass Flow Measurement

A mine has to sample the plant feed material and measure the mass flow from the shaft to the plant if a Shaft Call Factor (SCF) and a Plant Call Factor (PCF) have to be calculated. Calibration of the leach feed flow meter and densitometer is usually performed weekly. A small error in mass flow measurement calculates to a substantial effect in metal accounting. The calibration procedure is known as a rise test which entails filling a tank while collecting samples from the pulp stream. The liquid-solid determinations on the samples taken are compared to the densitometer readings. The volume can be calculated by pre- and post-filling measures of the slurry in the tank. Some plants obtain accurate measurements of tonnage and volume by diverting the flow to a calibration tank, i.e. a tank with known capacity installed on load cells.

Head and Residue Grade Sampling

The plant head grade is usually the core of a metal accounting system. Other grades, e.g. plant feed- and residue grade are related to the head grade by means of a factor. The head grade sample is typically a pulp sample taken from the slurry stream after the mills but before leaching. The pulp stream is considered to be homogenous compared to the broken rock on the plant feed conveyor. The head grade is therefore valued to be a more accurate estimation of the true grade. The head grade sampler and subsequent processes should for that reason be faultless. The acceptable standard was set according to the requirements for head- and residue grade sampling as presented by Spangenberg (2007) and summarised in section 4.4.4.

Primary sampling

The value of a grab sample is only applicable to the aliquot that was assayed as explained in 2.4. The values of manual samples are biased and cannot be used for metal accounting purposes. A poppit sampler belongs to the group of samplers that comply with the first mode of sampling and is therefore biased by design. This type of sampler is mounted on the side of a tank or pipe. It has a plunger that moves into the slurry at regular intervals and samples part of the flow part of the time. Figure 4.41 shows an example of a poppit sampler and mass flow meters, i.e. flow meter and densitometer.

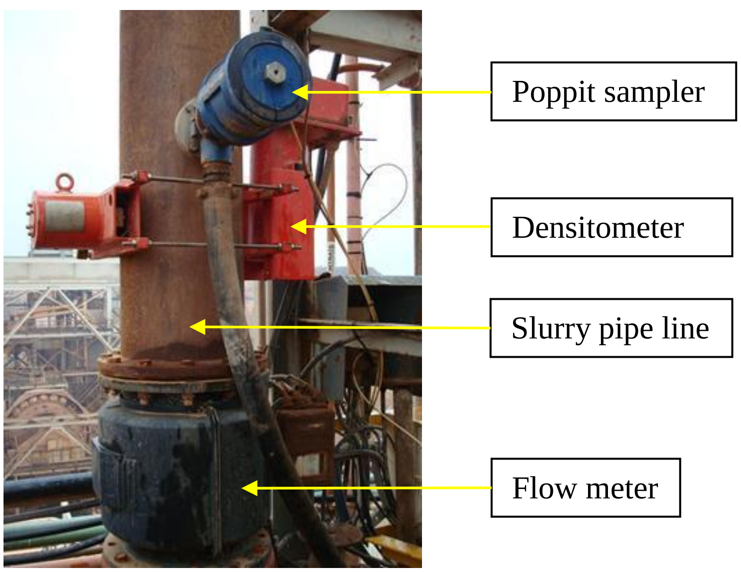

Figure 4.41 A poppit sampler, densitometer and flow meter installed in a slurry pipe line

A cross-stream sampler will deliver an unbiased sample if the sampler was designed, installed, operated and maintained correctly. The integrity of the sample should also be preserved. The cross-stream launder sampler and 2-in-1 type samplers belong to the third mode of samplers as described in 2.4. This type of sampler has a collector that moves across the slurry stream at regular intervals and samples the complete stream part of the time. The 2-in-1 sampler consists of the primary cross-stream sampler that is mounted in a vertical open ended downward flow line and a secondary Vezin-type sampler which is attached to the unit. Figure 4.42 displays examples of a cross-stream launder sampler and 2-in-1 sampler as designed by Multotec. Drawings and descriptions of these samplers can be found in Spangenberg (2007).

Figure 4.42 A cross-stream launder sampler on the left and a 2-in-1 sampler on the right (as manufactured by Multotec)

Secondary sampling

Sub-sampling is generally performed by means of a Vezin-type rotary splitter. Samplers that merely imitate Vezin and linear type samplers are usually biased and should not be used, for example:

- A flexible discharge tube periodically moved by a piston.

- A rotating tube divider, i.e. a distribution spigot passing over or in front of a fixed opening.

These samplers are biased because the flow of material is imparted a momentum other than the sole acceleration of gravity, resulting in complex and uncontrollable fluid mechanics conducive to sample incorrectness.

A Vezin sampler belongs to the category of a uniformly rotating cutter that takes a full cut of a vertical stream of material in free fall. Spangenberg (2007) described this type of sampler and included a drawing. Figure 4.43 shows the collectors of a Vezin-type sampler. The cutter opening of one of the rotating collectors is parallel and would therefore collect a biased sample. The collector opening should be radial. The radial opening of the other collector conforms to the requirements for a correct sampler.

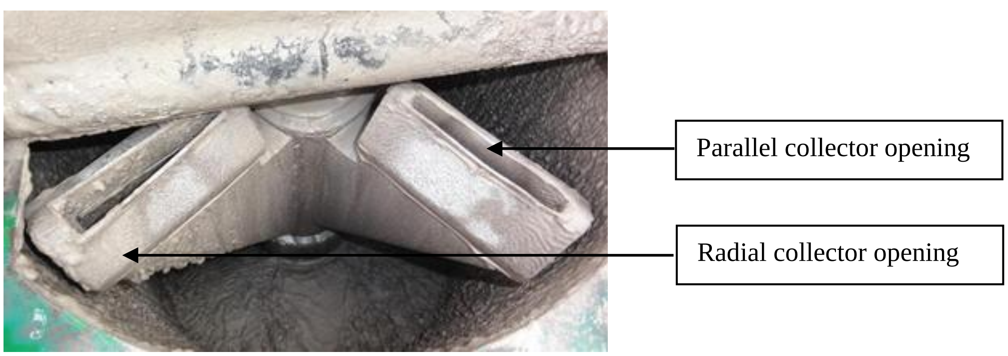

Figure 4.43 The collectors of a Vezin-type sampler

Cascade rotary splitters and riffle splitters are useful apparatus to split the sampled material after drying. However, the operating procedures should be meticulously followed to eliminate preferential sampling. François-Bongarçon (2002) explained during a short course presented at WITS that the variance of a riffler is ±100% compared to ±2% of a rotary splitter. However, it is time consuming to use a rotary splitter for the amount of samples that has to be processed. Sometimes the wet filter cake is divided before drying. This entails filtering of the slurry sample, collecting the filtrate, washing and re-pulping of the solids, re-filtering and dividing of the moist filter cake. One section or combined opposite slices of the cake is collected as the sub-sample.

4.4.3 Observations

The spread sheet provided for information to be recorded on the mass flow system. These instruments usually form the centre of mass measurement in the metal accounting system and it could be noted if it was used as the primary mass flow value. The ore is milled to ±80% passing 75µm. The milled material is thickened before the slurry is pumped via the mass flow instruments and head sampler to the leach area.

Mass Flow Measurement

Six mines do not use weightometers to measure the amount of ore delivered by the mines to the plants. One mine uses a single-idler weightometer, 24% has two-idler-, 33% has four-idler- and 10% have six-idler weightometers for this measurement. Only six-idler weightometers are considered sufficiently accurate for metal accounting purposes as discussed in 4.3.2. Flow meters and densitometers in the head lines of 67% of the plants are used as primary mass flow measurement instruments. The rest of the plants have poorly maintained slurry mass flow equipment.

Head Sampling

The spread sheet allowed for the following elements of head grade sampling in the metallurgical plant to be rated as shown in Table 4.14:

Table 4.14 Summary of the average potential influence of specific sampling errors on elements of head grade sampling

		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									Average Potential Influence			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
3	**METALLURGICAL PLANT**													
3.1	**Head grade sampling**													
	Grab		4.3	5.0	5.0	5.0		5.0	5.0		4.9	5.0	97.8	High
	Poppit		5.0	5.0	5.0	5.0		5.0	5.0		5.0	5.0	100.0	High
	Cross-stream : launder		3.0	3.2	2.8	3.6		4.3	3.7		3.4	5.0	68.7	High
	2-in-1		3.0	3.0	2.5	2.8		4.0	4.0		3.2	5.0	64.4	Moderate
	Other													
	Average for sub-section in %		76.7	81.0	76.5	82.2		91.5	88.5				82.7	High
	Sub-sampling													
	vezin-type		3.0	3.0	1.9	3.1	2.8	1.0	1.0		2.3	5.0	45.3	Moderate
	cascade rotary splitter													
	riffler													
	filter cake		3.0	5.0	5.0	5.0	5.0	1.0	5.0		4.1	5.0	82.9	High
	other: grab / cone & quarter		5.0	5.0	5.0	5.0	5.0	5.0	5.0		5.0	6.0	100.0	High
	Average for sub-section in %		73.3	86.7	79.6	87.6	85.3	46.7	73.3				76.1	High
	Average for section in %		75.0	83.8	78.0	84.9	85.3	69.1	80.9				**79.4**	**High**

Note : An empty cell indicates that the element of sampling was not encountered.
Potential influence of sampling error is low = 1, medium = 3 or high = 5.
(0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high

Table 4.14 is a summary of the average potential influence of the relevant sampling errors on elements of head grade sampling. Three metallurgical plants perform grab sampling and two use poppit samplers. The potential influence of all the sampling errors namely FSE, GSE, IDE, IEE, IPE, PIE and IWE is high. All the other operations use 2-in-1- or launder samplers to collect cross-stream samples. The potential influence of the sampling errors was rated as high for launder samplers and moderate for 2-in-1 samplers respectively.

Figure 4.44 displays the three grab sampling tools that are used to collect hourly specimens from the flow to the first leach tank at the three metallurgical plants. The increments are composited into a daily head sample. The poppit sampler in Figure 4.41 is mounted on the side of the leach feed flow line for the purpose of collecting a daily head sample. The potential influence of the IDE is high as the increment to be extracted is not a cross section of the slurry flow in either of the two methods. The potential influence of the IEE is high as the collectors are incorrectly designed and can never extract a correct sample. The potential influence of the IWE is also high as the sampling is not proportional. The PIE is high because the sampling frequency was chosen for logistical reasons, i.e. to collect a specific amount of pulp. It is evident that all the sampling errors as named above have a large potential contribution to the TSE.

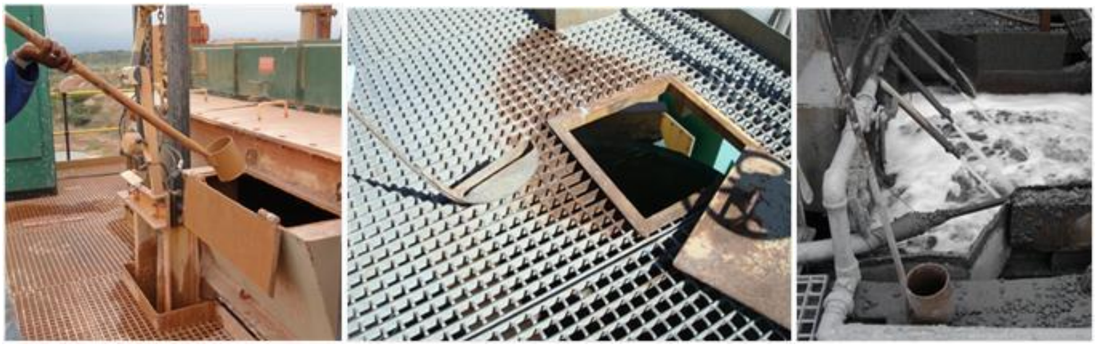

Figure 4.44 Grab sampling tools

Figure 4.45 illustrates the collectors of different cross-stream samplers moving through the falling pulp stream. The cutter on the left is engulfed by the slurry which flows over, under and out of the collector. The collector in the middle cannot accept all the particles in the stream as the opening is covered by a screen. The purpose of the screen is to prevent rock chips from entering the collector and subsequently choking the outflow line. These are good examples of incorrect samplers as all the particles in the pulp do not have the same probability to be selected in the sample and therefore the IDE, IEE and IWE have a high potential influence on primary sampling. The cutter on the right is adequately sized to accept the entire cross cut of the non-turbulent stream.

Figure 4.45 Examples of cross-stream slurry sampler collectors

Vezin-type sub-samplers are in operation at 71% of the plants and the potential influence of the sampling errors was rated as moderate. The remainder of the plants reduce the primary head sample by dividing the filter cake, coning-and-quartering and grab sampling. The influence of the GSE, IDE, IEE, IPE and IWE were high and therefore the total influence of all the sampling errors was rated as high.

Coning-and-quartering is usually performed incorrectly as the dried pulp is only rolled from the one side of the paper to the other. This action enhances separation of particles with different densities, i.e. enlarge the GSE instead of promoting proper mixing. Sample collectors that are designed and operated incorrectly contribute to the IDE, IEE and IWE.

Figure 4.46 shows the collectors of Vezin-type sub-samplers. These samplers were designed correctly but operated incorrectly. The samplers lack a cleaning cycle that should keep the radial collectors free of accumulated material. The partially blocked collector opening will collect an incomplete increment and hence a biased sample.

Figure 4.46 Collectors of Vezin-type samplers

Head sampling in the mill discharge

This position of the head sampler was encountered at one mine only. The sample is collected by means of a cross-stream sampler in the mill discharge launder. The discharge screen in the mill retains particles bigger than ±25mm. A grid on the collector opening of the sampler screens metal and stones. The apertures of the screen are 10mm squares. The mill discharge stream overflows the collector, i.e. the complete stream is not sampled. Particles fall below the collector and splash over the top of the collector. The mill discharge stream is very turbulent at the sampling point and therefore excessive splashing occurs. The collector was designed incorrectly and therefore the sample will always be biased as the IDE, IEE and IWE are very prominent.

The secondary sampler is of the Vezin-type. The down pipe from the primary sampler was choked by stones and metal pieces. No primary or secondary cleaning system is installed. The picture on the left of Figure 4.47 indicates the installation of the sampler and the picture on the right shows the primary collector in the parked position.

Figure 4.47 Mill discharge launder where cross-stream sampler is installed

Head sampling in the leach feed

Several plants use the Multotec 2-in-1 sampler and at a particular plant it is installed in the thickener underflow line to the first leach feed tank as shown in Figure 4.48.

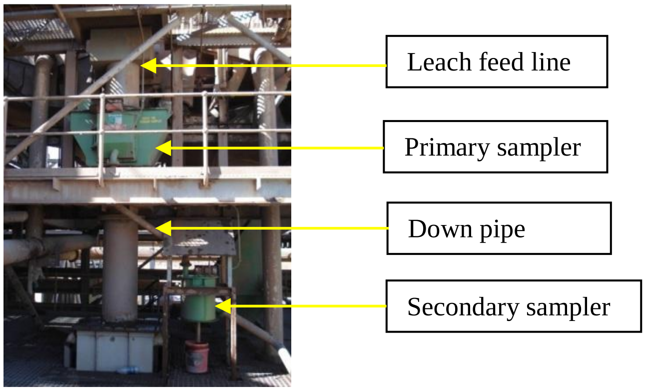

Figure 4.48 Leach feed sampler

It is assumed that the primary collector blades were parallel when it was manufactured and installed. Currently the opening is inverse radial as revealed in Figure 4.49. It decreases in width as the distance from the centre point increases (estimated 2cm decreasing to 1cm). Both the original and current conditions of the collector are unacceptable as it will produce a biased sample. The collector opening should be radial increasing in width from the spill point. The sample will always be biased as the collector was designed incorrectly. The IDE, IEE and IWE are evident.

The secondary Vezin-type sampler has four collectors that run continuously. No cleaning system is installed and solids accumulate on the collectors as shown in Figure 4.49. This build-up will gradually decrease the cutter opening and hence promote the IDE and IEE. A set of spray nozzles installed on each side of the stream can alleviate this problem. It should be installed in such a way that the spray water covers the complete length of the primary collector. The cleaning cycle should commence after each cut and only when sufficient time was allowed for the sample to pass the secondary sampler. Potable water should be used in the cleaning cycle. The secondary cleaning cycle should be initiated manually once per shift when the sample container is removed and the hatch of the holding bay is closed. A pressure switch in the holding bay should interlock the cycle to prevent accidental discharge of water into the sample container.

During normal operation the leach feed is sampled at five minute intervals and a composite sample is collected every four hours. The pulp is filtered, the wet cake divided, split into duplicate samples and the solids and solution are submitted for analyses. The sample should actually be called a specimen as it is incorrect as per definition.

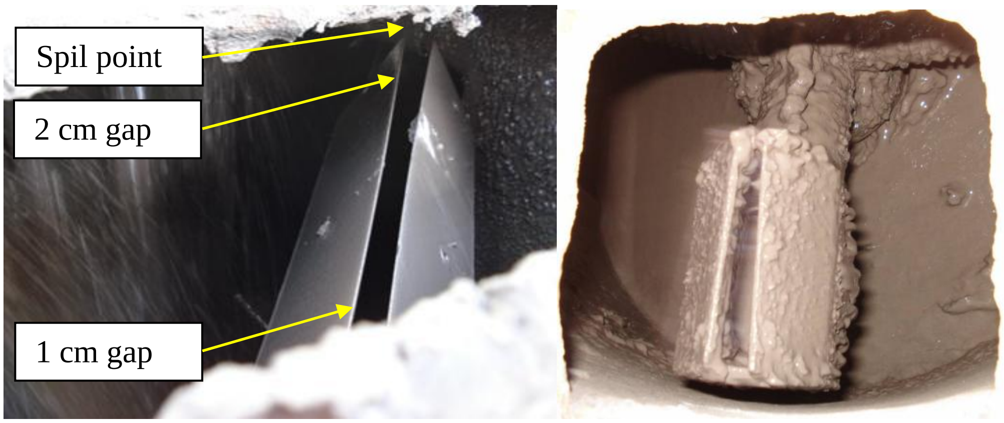

Figure 4.49 Primary collector on the left and secondary collector on the right

Summary

The average potential influence of the sampling errors was rated as high at 79.4% on elements of head grade sampling. Figure 4.50 presents the average potential influence of the relevant sampling errors on elements of head grade sampling and sub-sampling.

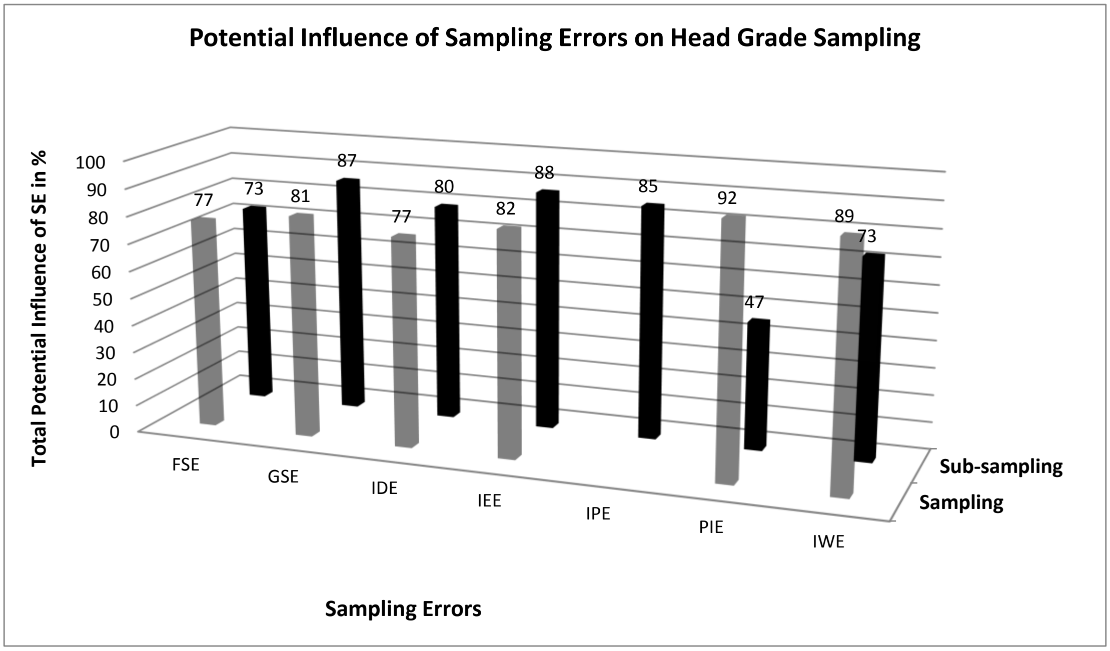

Figure 4.50 Average potential influence of specific sampling errors on sampling and sub-sampling elements of head grade sampling

Residue Sampling

Spangenberg (2007) specified the acceptable standard for the accurate measurement of the residue grade. The residue value is used in the metallurgical recovery calculation and gives an indication of the amount of precious metal that is sent to the tailings storage facility. The spread sheet provided for the rating of following elements of residue grade sampling in the metallurgical plant as shown in Table 4.15:

Table 4.15 Summary of the average potential influence of specific sampling errors on elements of residue grade sampling

		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									**Average Potential Influence**			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
3	**METALLURGICAL PLANT**													
3.2	**Residue grade sampling**													
	Grab		4.3	5.0	5.0	5.0		5.0	5.0		4.9	5.0	97.8	High
	Poppit		5.0	5.0	5.0	5.0		5.0	5.0		5.0	6.0	100.0	High
	Cross-stream : launder		3.5	3.5	3.6	4.3		4.4	4.4		3.9	5.0	78.8	High
	2-in-1		3.0	3.3	3.5	3.8		4.7	4.2		3.8	5.0	75.0	High
	Other													
	Average for sub-section in %		79.2	84.2	85.6	90.4		95.2	92.7				87.9	High
	Sub-sampling													
	vezin-type		3.0	3.2	2.7	3.6	3.2	1.0	1.0		2.5	5.0	50.3	Moderate
	cascade rotary splitter													
	riffler													
	filter cake		3.5	4.0	5.0	5.0	4.3	2.0	5.0		4.1	5.0	82.1	High
	other: grab		5.0	5.0	5.0	5.0	5.0	5.0	5.0		5.0	6.0	100.0	High
	Average for sub-section in %		76.7	81.0	84.6	90.8	82.7	53.3	73.3				77.5	High
	Average for section in %		77.9	82.6	85.1	90.6	82.7	74.3	83.0				**82.7**	**High**

Note : An empty cell indicates that the element of sampling was not encountered.
Potential influence of sampling error is low = 1, medium = 3 or high = 5.
(0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high

A cross-stream sampler conforms to the third mode of sampling as described in 2.4. It consists of a mechanical device that samples the complete vertical falling pulp stream at regular intervals without interruption of the plant process. A properly installed cross-stream sampler used in appropriate conditions can guarantee correct samples. The insertion of the cutter in the stream does transform the mechanics of fluids and solids nearby the collector in an unpredictable manner but the mechanics is simple enough so that limiting conditions of use that relate to collector opening width and cutter speed can be determined to guarantee negligible effects.

The findings were similar to those discussed for head grade sampling. Table 4.15 is a summary of the average potential influence of the relevant sampling errors on elements of residue grade sampling. Three metallurgical plants sample the pulp leaving the plant by means of grab sampling and four plants use poppit samplers. The potential influence of all the sampling errors namely GSE, IDE, IEE, IPE, PIE and IWE is high. All the other operations use 2-in-1- or launder samplers to collect cross-stream samples. The potential influence of the sampling errors was rated as high for both types of samplers.

Vezin-type sub-samplers are used by 62% of the plants and the potential influence of the sampling errors was rated as moderate. The remainder of the plants reduce the primary sample by dividing the filter cake or collecting a grab sample. The influence of the IDE, IEE, IPE and IWE were high and the result is that the total influence of all the sampling errors was rated as high.

Visit

During one of the visits to a metallurgical plant it was found that the cross-stream sampler was not in operation as the power to the sampler was off. The primary collector was stationary in the stream. The sample bucket contained no sample although it was halfway through the morning shift. It means that the secondary sampler stopped out of the stream or that either the down pipe or the collectors were completely blocked. Figure 4.51 presents the status of the sampler.

Figure 4.51 Stationary primary collector and sample bucket

It was reported that the operator visits the sampler during each shift and reports any problems. Mechanical inspections and repairs are carried out on request of the operator and according to a weekly planned maintenance program. The power to the sampler was restored and the sampler operation checked. The flow was non-turbulent at the point of sampling and did not cause any flow over the collector or excessive splashing. However, the pelican-type collector causes an outflow at the bottom of the collector. A shiftly composite sample is collected at a frequency of one cut every 18 minutes. No cleaning system is installed on the primary- or secondary sampler. The inspection hatch on the Vezin-type secondary sampler is inadequate as displayed in Figure 4.52. It could not be seen if the secondary collector openings are radial and clean. The build-up of material on the sampler indicates that the collectors might be choked. The sampler provides for duplicate samples to be collected even though only one sample container was present.

Figure 4.52 Secondary sampler and view inside inspection hatch

The primary collector and secondary sampler should be replaced by a cross-stream sampler that conforms to the requirements for a correct sampler as listed in the section on “Requirements for accurate plant head- and residue sampling” in the article by Spangenberg (2007). This sampler includes a cleaning system and control panel. The sampler is capable of collecting a correct sample if it is installed, maintained and operated correctly.

The operator should do 2-hourly inspections of the samplers. A checklist similar to Appendix 8 in Spangenberg (2007) should be completed at the start and end of each shift. An accounting sample is so important that it should be endeavoured to repair a sampler breakdown within the same shift it occurred. A frequency of one cut every 18 minutes is inadequate to cater for variance in the pulp stream e.g. fine carbon break through. The frequency should be increased to not less than once every five minutes (Bartlett and Hawkins, 1987).

The graph in Figure 4.53 presents the average potential influence of the relevant sampling errors on elements of residue grade sampling and sub-sampling.

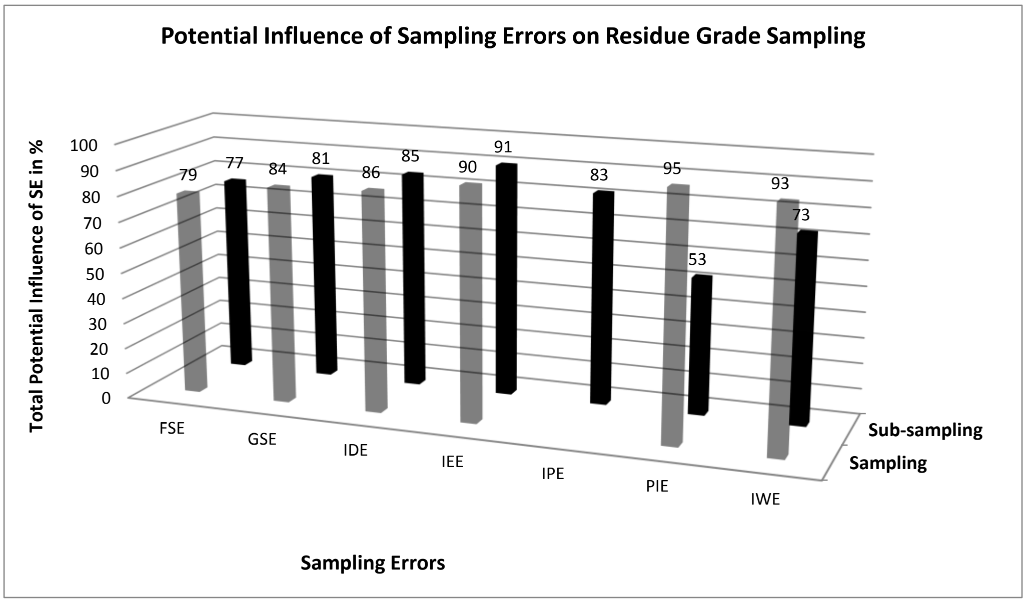

Figure 4.53 Average potential influence of specific sampling errors on sampling and sub-sampling elements of residue grade sampling

Bullion Sampling

The spread sheet provided for the following elements of bullion sampling in the metallurgical plant to be rated as shown in Table 4.16:

Table 4.16 Summary of the average potential influence of the specific sampling errors on elements of bullion and laboratory sampling

		Rating of Potential Influence of Sampling Errors (1 = low ; 3 = medium ; 5 = high)									Average Potential Influence			
	Sampling area & element of sampling	INE	FSE	GSE	IDE	IEE	IPE	PIE	IWE	AE	marks	out of	%	rating
3	**METALLURGICAL PLANT**													
3.3	**Bullion**													
	Dip			4.0	1.0	2.0					2.3	5.0	46.7	Moderate
	Drill			4.0	1.0	3.0					2.7	5.0	53.3	Moderate
	Other													
	Average for section in %			80.0	20.0	50.0							**50.0**	**Moderate**
4	**LABORATORY**													
	Aliquot selection				3.0	5.0	5.0			2.8	3.9	5.0	78.8	**High**
	Average for section in %				60.0	100.0	100.0			55.2			**78.8**	**High**
Note :	An empty cell indicates that the element of sampling was not encountered.													
	Potential influence of sampling error is low = 1, medium = 3 or high = 5.													
	(0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high								**Total rating for all sections:**				**73.7**	**High**
									Potential influence of sampling errors:					**High**

The bullion is dip-sampled by inserting the tip of a vacuum sealed glass tube into the melted bullion. The glass melts and the tube is filled with fluid metal. The tube is immersed in water to cool and solidify the sample. Drilling of bullion bars is a laborious but more correct method. The bar should be drilled right through in a randomly chosen position and not where a "soft spot" is found that can be easily drilled. The bullion bar in Figure 4.54 was drilled 18 times. The drill penetrated only a few millimetres as an amalgam of several metals formed an extremely hard product that could not be easily drilled with a hand held unit. A mounted heavy duty drill is suitable for the task.

Figure 4.54 Bullion dip samples on the left and a drilled bullion bar on the right

Part of Table 4.16 is a summary of the average potential influence of the relevant sampling errors on elements of bullion sampling. Two metallurgical plants sample bullion by means of dip sampling and 90% of the plants use drilling. The bullion in the smelter and in the final bar contains impurities in the form of metals and would therefore be segregated. The potential influence of the GSE was rated as high. The potential influence of the IDE was rated as low as the sampling tools were well developed and no other means could be found to perform this type of sampling. The potential influence of the IEE was rated as moderate as most of the mines perform bullion sampling meticulously. The potential influence of all the sampling errors encountered at bullion sampling was moderate. Figure 4.57 presents the average potential influence of the relevant sampling errors on bullion sampling.

4.4.4 Conclusions

Head- and Residue Grade Sampling

The high potential influence of all the sampling errors rated is a concern as head grade sampling is the core of the metal accounting system. Some companies have a code for the reconciliation of produced grade and tonnage. These codes demand due diligence in terms of mass flow measurement and sampling for metal accounting purposes. Three metallurgical plants perform grab sampling and two use poppit samplers to collect head grade samples. Three operations sample the pulp leaving the plant by means of grab sampling and four plants use poppit samplers. These plants collect biased samples and the potential influence of all the sampling errors were rated at maximum hence the effect on the average calculations as displayed in Table 4.15.

A few years ago, Anglogold Ashanti and Multotec embarked on a program to develop a cross-stream sampler that conforms to the theoretical requirements of a correct sampler (Spangenberg, 2007). The design was endorsed by François-Bongarçon and has since been installed at 12 of the metallurgical plants visited. Incorrect sampling is inexcusable considering the enormous impact of decisions made based on incorrect sample values and the fact that the technology and specialist advice are available.

Bullion Sampling

The bullion produced by the metallurgical plants is delivered to refineries for purifying and marketing of the final product. All the refineries sample the molten bullion by means of dip sampling. The mines are compensated according to these sample values and not their own results attained via drill or dip sampling. The dip sampling method is used even though it is incorrect as all the particles in the melting pot do not have the same probability to be selected in the sample by the glass tube. However, it is considered to be time saving and also more correct than partial drilling of the bullion bar.

Summary

It is concluded that the acceptable standard should be set according to the requirements for slurry sampling as described by Bartlett and Hawkins (1987), Pitard (2005), Spangenberg (2007) and Holmes (2009):

- Cross-stream launder sampler. The flow rate of the stream should be between 2m/s and 10m/s. The stream in the launder should be non-turbulent at the point of sampling to minimise splashing when the collector moves through the stream. The collector size and drain system should be adequate to accept the full flow during sampling. The blades of the collector should be of stainless steel and fixed parallel 10mm or more apart. The collector should start outside the stream and reach constant speed before entering stream. The speed of the collector should not exceed 0.6m/s. The motor should be sized to maintain a constant speed inside the stream. The collector should move through the entire stream and stop outside the stream away from any splashing. The collector should be adequately sized to accept the entire crosscut of the stream. The collector blades should move at a right angle to the stream.

- Inline 2-in-1 sampler and Vezin-type sampler. The unit should be installed in a vertical gravity flow line. The cutter edges of the collector should be radial with respect to the centre of rotation and a minimum 1cm apart. The distance between the stream discharge and the cutter edges should be more than 2cm. The angular speed of the tip of the collector should be less than 45cm/s for units with a diameter larger than 60cm and less than 30cm/s for smaller diameter samplers. The distance between the farthest point from the axis where the stream is cut and the outer end of the collector should be a minimum 5cm. The same requirement applies to the distance between the inner end of the collector and the point where the stream is intercepted. The blades should be symmetrical and blunt with a flat area of ±0.75mm. The outer slope of the blades should be at an angle of $\pm 70^{o}$. The capacity of the collector and the discharge should be sufficient to cater for the entire cross-cut of the stream.

- Cleaning. An adequately sized inspection door should allow for unobstructed viewing of the collectors. A set of spray nozzles should be installed on each side of the stream in such a way that the spray water covers the complete length of the blades. Potable water should be used in the cleaning cycle.

- Bullion sampling. All the refineries sample the molten bullion by means of dip sampling which is theoretical incorrect but more acceptable than partial drilling. Drill sampling is correct when the bar is drill right through in random selected positions.

4.5 Laboratory Sampling

4.5.1 Literature

François-Bongarçon (2002) recommended dip sampling as the preferred method to select the final aliquot from the milled sample for assay. The entire milled sample should be removed from the packet, placed on a sheet of paper and blended by rolling. The material should be flattened and grid marked. Portions of sample should then be randomly selected by dipping to the sheet using a thin bladed spatula. The action is repeated until the aliquot mass is obtained.

4.5.2 Guideline

This dip sampling method is considered by most laboratories as best practice since it gives the entire sample an equal opportunity of being selected as the portion of sample for assay. Some laboratories find the method too time consuming and accepted a short method. The Laboratory Guideline (Maree, 2007:2) specifies that: "Multiple portions of the sample are removed with a thin bladed spatula while holding the packet at an angle, running the spatula down the entire side of the packet and lifting upwards. This procedure is repeated until the desired aliquot mass is obtained." The sample in the bag should not be stirred in an attempt to mix it as this will enhance segregation.

4.5.3 Observations

The spread sheet noted aliquot selection as the only element of sampling to be rated in the laboratory as listed in Table 4.16. At one laboratory the analyst attempted to select the final aliquot by means of dip sampling as recommended by François-Bongarçon (2002). It was evident that the person was unfamiliar with the technique as he might have been instructed on short notice to use it. The method is shown in Figure 4.55.

The procedure of most laboratories state that multiple portions of a sample should be removed by means of a thin bladed spatula while holding the packet at an angle, running the spatula down the entire side of the packet and lifting it upwards as presented on the right in Figure 4.55. This procedure is repeated until the desired aliquot mass is obtained.

Figure 4.55 Examples of aliquot selection in a laboratory

Neither of these methods is performed methodically as it is time consuming and the operator will usually follow the short route, e.g. pouring from the packet or using a spoon as exposed in Figure 4.56.

Figure 4.56 Examples of incorrect methods of aliquot selection in a laboratory

Part of Table 4.16 is a summary of the average potential influence of the relevant sampling errors on aliquot selection. Aliquot selection was specifically rated in all the laboratories and the potential influence of the sampling errors was found to be high with IEE and IPE as the main contributors as shown in Figure 4.57.

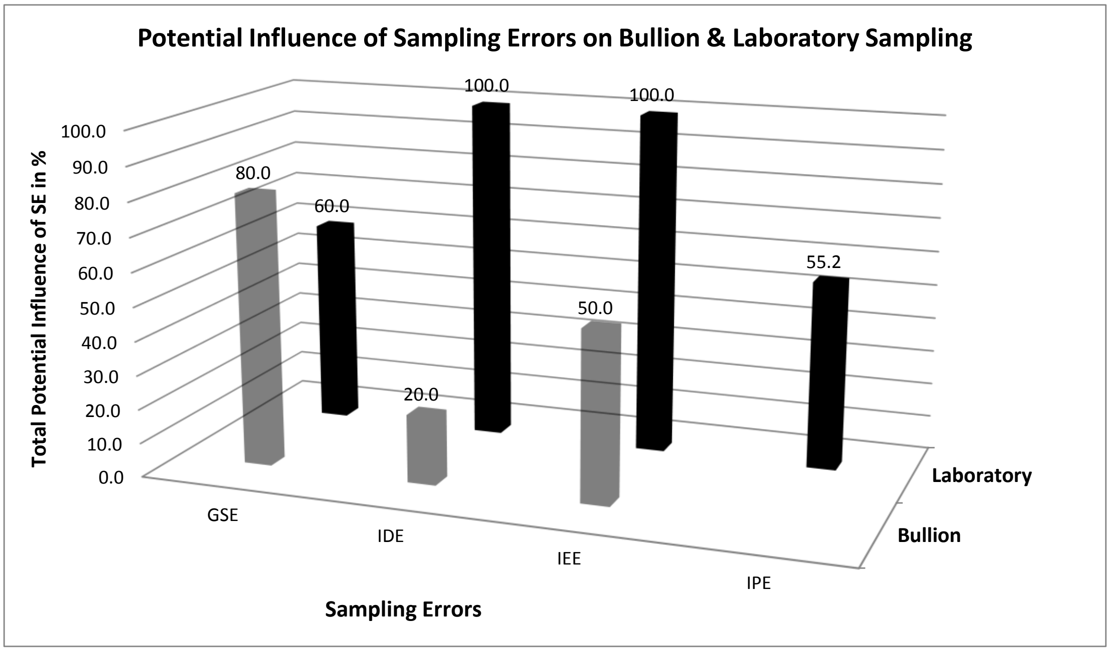

Figure 4.57 Average potential influence of specific sampling errors on sampling elements of bullion and laboratory sampling

4.5.4 Conclusions

Sub-sampling in the laboratory has been the point of discussion in many forums and audit reports. The personnel in the laboratory believe that the crushed and pulverised sample is already well mixed and therefore taking an aliquot from the mill bowl or sample bag can be done with any instrument e.g. a spoon. François-Bongarçon (2002) recommended dip-sampling and certain laboratories in the RSA accepted the thin-bladed spatula method. Neither of these methods is performed methodically as it is time consuming and the operator will usually follow the short route, e.g. pouring from the packet. It would have been ideal to use a cascade rotary splitter but production pressure will sanction this. The IDE and IPE have high potential influences on laboratory sampling practice.

It is concluded that a cascade rotary splitter should be used when a minimal number of samples are assayed, e.g. exploration and plant samples. Rotary splitting may be replaced by dip sampling. The tilted packet method may be used by laboratories that analyses large numbers of samples, e.g. grade control samples.

4.6 Management

4.6.1 Literature

Pollard et al (2009) explained that from their experience in industry, education, training and professional development, the minerals industry regards sampling as an important part of its operations, but often does not recognize the differences between good and bad sampling practices. They list the reasons as: poor understanding of sampling theory and how it should be applied, a corporate cost saving culture especially concerning technical issues which are not well understood by executive management and a failure in the education of industry professionals to develop an understanding of the fundamentals and economic importance of good sampling practice.

4.6.2 Guideline

Code of Practice

The way of thinking of managers regarding sampling practices should be guided by a Code of Practice (COP) which exists, preferably, at corporate level in the company. The COP details the requirements of samplers for specific purposes, e.g. broken ore sampling, pulp sampling for metal accounting and grade control sampling. The COP should specify design, installation, operation and maintenance requirements according to the TOS. The COP has a high potential influence on sampling practice and exists in 76% of the mines visited.

Standard Operating Procedure

A documented Standard Operating Procedure (SOP) should be available for each sampler and its associated processes. The SOP serves as an instruction manual for the sampling operator and technician. Such documents were found in all the mines whom were guided by a COP. The SOP has a high potential influence on sampling practice.

Planned Task Observation

A Planned Task Observation (PTO) is carried out by checking the activities of the sampling operator or technician against a checklist which is based on the SOP. Any deviations from the SOP should be pointed out by the observer. Corrective action may be immediate on-the-job training or formal training. The PTO has a high potential influence on sampling practice and 71% of the mines perform PTO's.

Availability of Finance

A cost saving culture with regards to sampling and technical issues which are not well understood by management may have adverse effects on sampling practices. Finance should be available to ensure that the sampling equipment is installed, operated and maintained according to the requirements for a correct sampler. The availability of finance has a moderate potential influence on sampling practice as it was found that 52% of the mines do not have any capital to spend on sampling. These mines resort to grab sampling and inexpensive alternatives, e.g. poppit samplers. It was established that the managers are ill-informed with regards to good sampling practice and were satisfied with the advice from subordinates and salesmen. The former saved money as the manager ordered and the latter clinched the deal no matter what was required by the TOS. Ten mines out of the 21 visited have budgets to maintain existing samplers and related practices, e.g. buying of CRM. Only 10% of the mines were in a position to design and install new samplers to replace outdated equipment.

Internal Audits

Formal internal audits should be carried out regularly to ensure adherence to the COP. Deviations from the COP should be addressed on managerial level as the economic impact of poor sampling can be enormous. Internal audits has a moderate potential influence on sampling practice as it was found that only 43% of the mines do regular internal audits.

External Audits

Formal external audits should be conducted by a sampling specialist from outside the mining operation. These audits should, as a minimum requirement, be carried out annually. External audits has a moderate potential influence on sampling practice as it was found that all the mines arrange irregular external audits.

Training

It is imperative for the operations manager to attend a formal sampling course. An appreciation of the TOS by management will encourage a positive approach to elements of management that influences good sampling practices, e.g. the availability of capital for sampling equipment and training of operators. Formal training of management has a low potential influence on sampling practice while the in-house training of operators has a moderate influence. None of the operation managers attended any formal sampling courses. One senior manager attended a short course presented at WITS. Knowledge of the TOS enabled the manager to successfully motivate for a capital project to replace all outdated incorrect samplers at the specific mine. All the mines have on-the-job sample operator training.

Sampling Champion

A person with a sound knowledge of the TOS is an asset to the mining operation. This person can act as a sampling champion who teaches operators in the workplace how to operate and maintain a sampler according to the principles of correct sampling. The potential influence of the sampling champion on the mine is moderate as 43% of the mines have such a person. An external sampling expert should be consulted if a person, who is competent in the principles of sampling, does not exist at the mine or in the company. The potential influence of the external sampling expert is moderate as 29% of the mines seek advice from consultants. A supplier should honour the TOS in advising the client and should not merely turn a sampling requirement into a business transaction. The potential influence of suppliers is moderate as only 24% of the mines seek advice from salesmen.

4.6.3 Observations

Table 4.17 shows that the spread sheet provided for the following elements of management to be rated in terms of its potential influence on sampling practice:

Table 4.17 Summary of the average potential influence of management and related principles on sampling practices

Potential Influence of Management on Sampling Practice : Summary for all Mines				
Rating of Potential Influence on Sampling Practice (low = 1 ; 3 = medium ; 5 = high)				
Elements of Management	marks	out of	%	rating
Code of practice	4.0	5	81.0	high
Standard operating procedures	3.9	5	77.1	high
Planned task observations	3.7	5	73.3	high
Availability of finance	2.0	5	40.0	moderate
Internal audits	2.1	5	42.9	moderate
External audits	3.1	5	61.9	moderate
In-house training (operators)	3.0	5	61.0	moderate
Formal training (management)	1.0	5	20.0	low
Sampling champion : on mine	2.4	5	48.6	moderate
in company	3.9	5	77.1	high
consultant	2.0	5	41.0	moderate
supplier	2.0	5	39.0	moderate
Average	2.8	5	55.2	Moderate
Potential influence of management on sampling practice:			**55.2**	**Moderate**
Note : (0.0 - 33.3)% = low; (33.4 - 66.6)% = moderate; (66.7 - 100.0)% = high				

The graph in Figure 4.58 shows that the following elements of management have a high potential influence on sampling practices in the existing environment:

- COP, i.e. a documented Sampling Standard based on the TOS.
- SOP, i.e. a manual that describes the operating-, preparation- and maintenance procedures of each sampler.
- PTO, i.e. formal evaluation of the sampling operators at work.
- A sampling champion in the company and on the mine, i.e. a person who drives the quest for correct sampling.

The following elements of management have the potential to influence sampling practices but are medium to low-rated in the current situation and non-existing on some of the mines:

- The availability of finance for sampling and related practices.
- Regular internal- and external audits.
- Formal training of management in the TOS and subsequent in-house training of operators in the practical aspects of the subject.

The potential influence of management and related principles was rated as moderate.

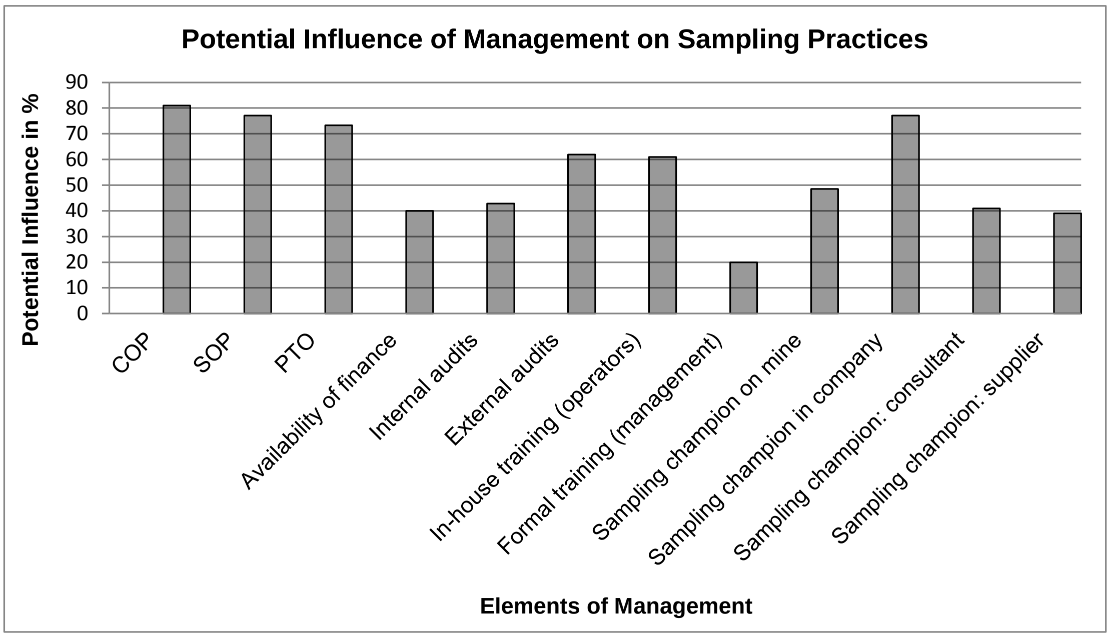

Figure 4.58 Average potential influence of management and related principles on sampling practices

4.6.4 Conclusions

Management should be the driving force behind good sampling practice. On some mines it was found that the lack of formal training in the TOS transpires in critical aspects e.g. the fact that funds are not allocated for the design, installation, maintenance and operation of correct samplers. Subsequent training of operators and audits are also not carried out. However, on most of the mines an awareness of the importance of good sampling practice does exist. The best available sampling equipment can usually be found in operation at these mines. Unfortunately it does not mean that the samplers are operated correctly. There are also mines that endeavour to upgrade their sampling systems but financial constraints impede immediate action.

Although the potential influence of management and related principles was rated as moderate, some elements have a high potential influence on sampling practice e.g. COP, SOP and PTO. It was found that these elements do exist on most of the mines and they are even more valuable where a sampling champion provides the momentum.

It is concluded that designated persons on the mine and in the company should ensure that the basic documentation that drives good sampling practice should be in order, i.e. COP, SOP and PTO. The champions should also ensure that operators receive the necessary training and inspiration. They should also perform regular audits and PTO. They should influence managers through informative presentations and reports to allocate capital to the development and maintenance of sound sampling equipment.

4.7 Total Potential Influence

4.7.1 General

It is reiterated that the potential influence of the relevant sampling errors on each element of the particular sampling system was rated. It is not a rating of the current performance of the specific sampling system or element thereof. Consider head grade sampling as an example and the potential influence of the IEE. Two extreme sampling methods were encountered namely grab sampling as opposed to a well-designed, installed, operated and maintained cross-stream sampler. The potential influence of the IEE is low for the latter type of sampler and 100% for grab sampling. All the other head samplers rated in between and the average potential influence for the IEE is 85% as shown in Table 4.14. This illustrates clearly that each mine should view its own spread sheet to rectify sampling deficiencies and minimise potential influences of specific sampling errors. The general picture highlights problem areas and will assist in standardising sampling practice in the Mining Industry.

4.7.2 Findings

The numbers in Table 4.18 present the general picture of the potential influence that the sampling errors might have on the sampling systems in specific areas. The average potential influence of the sampling errors on each element of the different sampling systems in the detailed areas was calculated from the spread sheets and converted to percentage with 5 being equal to 100%. The summary sheet, which is included on the compact disc, shows the average potential influence of the sampling errors on each element of the sampling systems in the particular areas. The summary sheet was presented in sections from Table 4.1 to Table 4.17.

Table 4.18 Potential percentage influence of sampling errors on sampling systems

Sampling errors	**Sampling systems**							
	Explo-ration	**Open-pit**	**Under ground**	**Broken ore**	**Head grade**	**Residue**	**Bullion**	**Laboratory**
INE	79	87	96					
FSE	60	80	60	71	75	74		
GSE	39	83	60	100	84	80	80	
IDE	20	65	100	97	78	83	20	60
IEE	44	70	100	100	85	89	50	100
IPE	49	67	100	100	85	83		100
PIE				99	69	74		
IWE				77	81	82		
AE								55
Total	45	78	84	92	79	81	50	79

The total potential influence of all the sampling errors on all the sampling systems was an average 73.7% which is rated as high. This number is shown in Table 4.16.

The total potential influence of all the sampling errors on the sampling systems as grouped per area is presented in Figure 4.59.

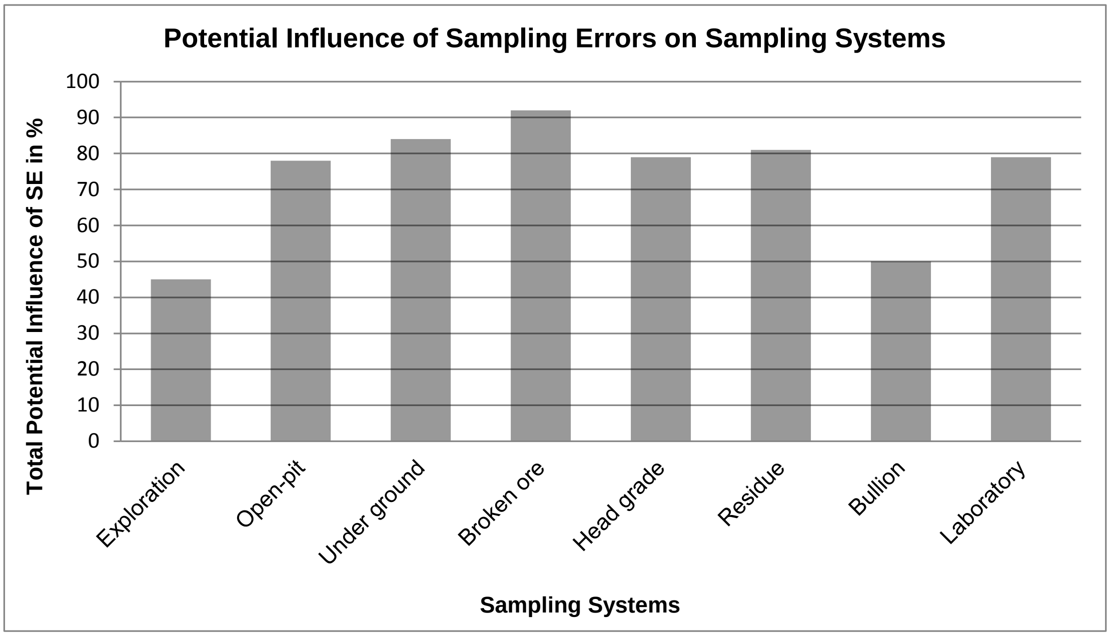

Figure 4.59 Total potential influence of all sampling errors on sampling systems in specified areas

5 CONCLUSIONS

The financial consequences of incorrect-, poor-, insufficient- or no sampling can be devastating. A bad blast hole sampling protocol that was erroneously implemented, cost a mine USD134 million over a 10-year period (Carrasco et al, 2004). They also reported that incorrect sampling of floatation tailings amounted to USD2 billion over a 20-year period for a specific mine. The exponential increase in the gold price, as displayed in Figure 5.1 (Anglogold Ashanti, 2011), would inflate these losses even more in current monetary values. Incorrect allocation of grade cannot be tolerated especially in the present economic climate where another possible recession is on the horizon. Unemployment is a global phenomenon.

Gold production declined over the last six years in South Africa as shown in Table 5.1 (USGS, 2011) and Figure 5.1. It is therefore of vital importance that the principles of the TOS should be applied from the exploration stage, through mining and metallurgical recovery to sampling of the final product, i.e. gold bullion and residue, to eliminate misclassification of grade. A small saving in terms of sampling practice might cost a company dearly in hidden costs as a result of incorrect decisions based on poor sampling practice. It could mean the difference between pursuing the exploration results and building a mine or deciding that the ore body is below the cut-off grade and the project is not feasible. In both cases millions of dollars are at stake as explained in Minnitt (2007). It involves capital expenditure, employment opportunities and foreign income.

Table 5.1 Gold production in South Africa

Year	2005	2006	2007	2008	2009	2010*
Mass in kg	294 671	272 128	252 598	212 744	197 698	190 000

* estimated

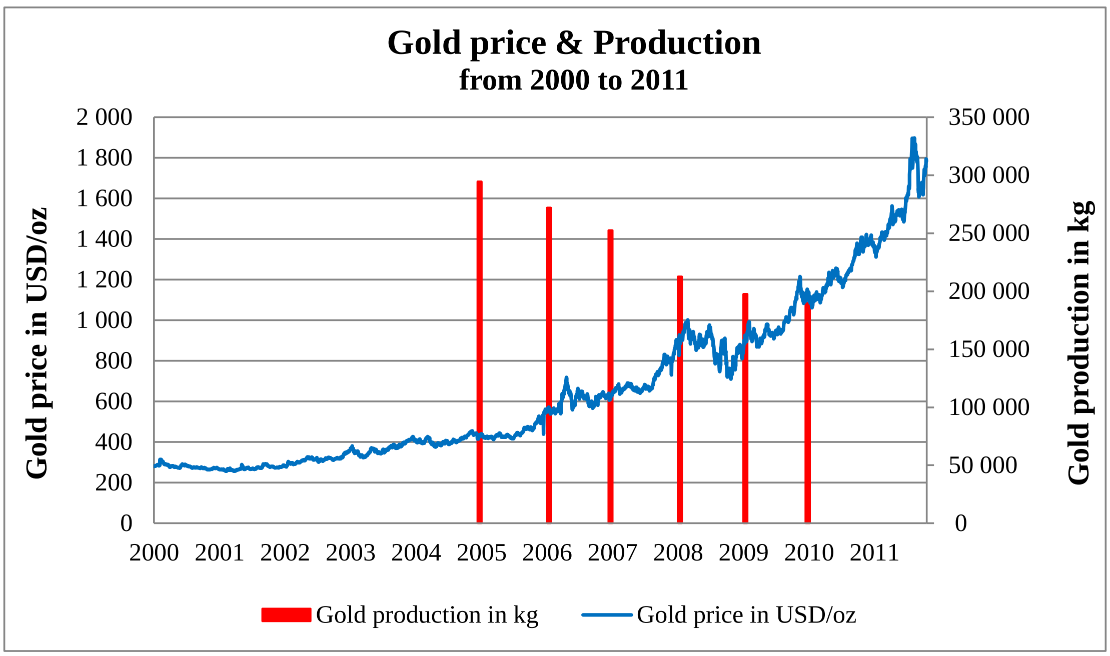

Figure 5.1 Gold price and South African gold production

The potential influence of the relevant sampling errors are high in all areas of sampling in this study except for exploration and bullion sampling where it was found to be moderate. This statement should be viewed with caution as explained in 4.7.1. Although the potential influence of management and related principles was rated as moderate, some elements have a high potential influence on sampling practice e.g. COP, SOP and PTO.

The study provided valuable information to understand the general status of sampling practice in the Gold Mining Industry in Africa. The potential influence of specific management principles and of the relevant sampling errors on each component of the particular sampling system was rated. Each mine can use the information to address weak points when they plan their way forward in terms of sampling practice. The information can also be used in a process to standardise sampling practices in the Mining Industry. An overview of the study was presented by Spangenberg (2011) at the Fifth World Conference on Sampling & Blending (WCSB5) and the general consensus was that standardisation of sampling practices is essential.

6 RECOMMENDATIONS

It is recommended that the following elements, as summarised in Table 6.1, should be used as a basis for an International Standard for Sampling Practices in the Gold Mining Industry. The table and subsequent description is a summary of the rules, principles and leading practice found in the theory, current operating procedures and practice. Available technology are listed and it is merely examples and not prescriptive.

Table 6.1 Basic elements of a sampling standard

Sampling Area	Primary sampling	Secondary sampling	Technology available
Exploration	Diamond drilling		Boart Longyear
		Diamond saw	Almonte automatic core saw
Open pit grade control	RC-drilling		Sandvik
		RotaPort™ cone splitter	Sandvik
Underground grade control	Chipping		Hammer, chisel & clino ruler
		Variable split sample divider	Material Sampling Solutions
Broken ore	Stop-belt (low volume)		In-house fabrication
	Go-belt and cross-stream (high volume)		Multotec hammer and Tru-Belt® sampler
		Rotary splitter	Multotec
Metallurgical plant head & residue pulp	Cross-stream launder	Vezin	Multotec cross-stream cutter & Vezin
	In-line 2-in-1	Vezin attached	Multotec 2-in-1
Bullion	Mounted drill & glass tube dipping		
Aliquot selection in laboratory	Dipping or rotary splitter (low volume); tilted packet (high volume)		

6.1 Exploration Sampling

6.1.1 Primary sampling

Diamond drilling should be used for primary sampling. The largest diameter drill that is practical possible, should be used.

6.1.2 Secondary sampling

Secondary sampling should be performed by means of a diamond saw and preferably an automatic unit similar to the automatic core saw that was developed by Almonte Diamond Pty Ltd (2011). Broken or brittle core should be crushed or milled before splitting by means of a rotary splitter. Meticulous core logging is an irrevocable part of the sub-sampling process and should be done according to the requirements of the specific code, e.g. SAMREC Code (2009) Section T3.

6.1.3 QAQC

QAQC is an integral part of any sampling process. The following elements are required:

- Standards. CRM should be included in the batches of samples destined for assay to monitor the accuracy of analysis.
- Blanks. Contamination and possible sample swops can be checked by incorporating blanks (barren rock).
- Duplicate sample analysis. These values will give an indication of the precision of the analytical process. Duplicate samples should also be submitted to a second laboratory. CRM and blanks must accompany these referee samples. The values will show the relative bias of the operational laboratory compared to the referee laboratory.

6.2 Open-pit Grade Control Sampling

6.2.1 Primary sampling

A RC-drill equipped with a cyclone, a drop box and an emission filter is the best method to do high volume grade control sampling. The drop box collects the sample via the cyclone during drilling of a specific interval, shuts off the flow to the box at the end of the drilled interval and drops the sample onto the cone under the force of gravity only. The rotating collectors collect the sub-sample.

6.2.2 Secondary sampling

A stationary cone splitter with rotating radial collectors should be used for secondary sampling. Sandvik Mining and Construction (2008) has developed and patented such a unit, the RotaPort™ cone splitter that is functional in wet and dry conditions. Material that hinders sub-sampling should be collected per increment via the cyclone and sun-dried before splitting by means of a single stage riffle splitter. The trap door of the loading pan of the riffler should open from the centre line. Selective sampling should be avoided by choosing the sub-sample at random and not from the same side of the riffler, for subsequent splitting if required.

6.3 Underground Grade Control Sampling

6.3.1 Primary sampling

The work and recommendations of Cawood (2003) should be considered when a sampling protocol for a narrow-reef or any other mine is constructed because he recognised that different standards is required for different gold mineralisations.

The Anglogold Ashanti standard for underground chip sampling that was compiled by Kelly (2006) and revised by Flitton (2009) contains the basic principles as described by Sichel (1947), Storrar (1987) and Cawood (2003) and should be used as guideline for chip sampling. The requirements for good sampling practice are listed under the following headings as discussed in 4.2.4:

- Sample area to be thoroughly clean.

- Segregation of reef and demarcation of sample areas.
- Measurement of sample widths.
- Chipping of samples.
- Delivery of samples.

6.3.2 Secondary sampling

The chip sample taken from the face is prepared in its entirety as it usually weighs less than 500g, i.e. no sub-sampling is performed before crushing and milling. The variable split sample divider should be used to collect a specific mass fraction from the original sample after crushing if the original sample mass exceeds the capacity of the mill bowl (Lyman and Simonato, 2008; Bamber, 2012).

6.4 Broken Ore Sampling

6.4.1 Primary sampling

The following sampling methods serve specific operational needs and should conform to the requirements of good sampling practice, i.e. correct sampling according to the TOS:

- Stop-belt sampling when low volume permits, i.e. manual sampling from a belt using a rigid frame to delimit the sample. The requirements are:
    - The minimum frame width is three times the nominal top size, D_{95} of the material on the belt.
    - The blades should follow the curve of the conveyor over the length of the frame i.e. the width of the conveyor.
    - The guides of the frame should be fixed to the conveyor bed.

- A complete extraction should be executed by removing all the particles including the fines.

- Cross-stream cutter, i.e. a collector that moves across the entire stream of free falling material at the end of a conveyor. The requirements are:
  - The collector should travel at a constant linear speed not exceeding 0.6m/s.
  - The collector opening should be at least three times the nominal top size, D_{95} of the particles and not less than 10mm for fine dry solids and a minimum of 50mm for wet solids.
  - The sides of the collector opening should be parallel.
  - The capacity of the collector should be sufficient to cater for the amount of material collected during the cross-cut.
  - The collector should away from the stream.
  - No material should remain in the collector after discharging the increment.

- Go-belt or hammer sampler, i.e. a cutter that moves across the entire conveyor collecting material from the belt while it is in operation. The requirements are:
  - A rubber lip must be installed on the cutter edge of a hammer sampler to ensure a clean sweep of the belt. Support below the conveyor can assist the cutter in collecting all the fines from the belt.
  - The collector sides should be parallel and the opening should be at least three times the nominal top size, D_{95} of the material on the belt.
  - The capacity of the collector should be sufficient to cater for the amount of material on the conveyor.
  - The motor should be powerful enough to ensure a constant speed while the collector cuts through the material.

The following elements are part of the sampling process:

- Weightometer. Only six-idler weightometers are considered sufficiently accurate for metal accounting purposes. The calibration should be checked weekly by carrying out a zero test, i.e. unloaded running conveyor and static weight test, i.e. running conveyor loaded with measured mass pieces or a calibrated chain.

- Frequency. Sample collection should be initiated when a pre-determined amount of ore passed the weightometer. The sampling frequency should be determined as described in 4.3.2.

- Detector. A detector should be installed to stop the belt when a large rock is detected. Oversize material should be removed from the conveyor to prevent chokes and damage to the go-belt sample collector and belt. Broken rocks should be loaded before the sampler to give it an opportunity to be sampled.

- Safety. The go-belt sampler should be enclosed to prevent injury from flying rock chips. Inspection doors should be available for access to all parts of the sampler.

6.4.2 Secondary sampling

Broken ore sample preparation involves sample mass reduction and particle size reduction. The sample preparation protocol, i.e. splitting at different top sizes, crushing and comminution should be determined by means of the nomogram procedure as described in 4.3.2 and 4.3.3.

6.5 Metallurgical Plant Pulp Sampling

6.5.1 Primary sampling

- The cross-stream launder sampler should conform to the following theoretical requirements for correct sampling:

- The flow rate of the stream in the launder should be between 2m/s and 10m/s. The stream should be non-turbulent at the point of sampling.
- The collector size and drain system should be adequate to accept the full flow during sampling.
- The collector should be adequately sized (long enough) to accept the entire crosscut of the stream. The collector blades should move at a right angle to the stream.
- The blades of the collector should be of stainless steel and fixed parallel 10mm or more apart.
- The collector should start outside the stream, reach constant speed before entering stream, move through the entire stream and stop outside the stream away from any splashing.
- The speed of the collector should not exceed 0.6m/s.
- The motor should be sized to maintain a constant speed inside the stream.

- Inline 2-in-1 sampler and Vezin-type samplers. The requirements are:

  - The unit should be installed in a vertical gravity flow line.
  - The cutter edges of the collector should be radial with respect to the centre of rotation and a minimum 1cm apart.
  - The distance between the stream discharge and the cutter edges should be more than 2cm.
  - The angular speed of the tip of the collector should be less than 45cm/s for units with a diameter larger than 60cm and less than 30cm/s for smaller diameter samplers.
  - The distance between the farthest point from the axis where the stream is cut and the outer end of the collector should be a minimum 5cm. The same requirement applies to the distance between the inner end of the collector and the point where the stream is intercepted.

- The blades should be symmetrical and blunt with a flat area of ±0.75mm. The outer slope of the blades should be at an angle of ±70°.
- The capacity of the collector and the discharge should be sufficient to cater for the entire cross-cut of the stream.
- The inspection hatch should be large enough to allow clear viewing of the collectors.

- Cleaning. It is required that:

  - An adequately sized inspection door should allow for unobstructed viewing of the collectors.
  - A set of spray nozzles should be installed on each side of the stream in such a way that the spray water covers the complete length of the blades.
  - Potable water should be used in the cleaning cycle.

6.5.2 Secondary sampling

The Vezin-type sampler as discussed in 6.5.1 should be used.

6.5.3 Bullion sampling

All the refineries sample the molten bullion by means of dip sampling which is theoretical incorrect but more acceptable than partial drilling. It is suggested that a bench mounted drill should be used to drill the bar right through in random selected positions.

6.6 Laboratory Sampling

It is suggested that a cascade rotary splitter should be used when a minimal number of samples are prepared for assay, e.g. exploration and plant samples. Rotary splitting may be replaced by dip sampling. The tilted packet method may be used by laboratories that analyses large numbers of samples, e.g. grade control samples.

6.7 Management

It is suggested that designated persons on the mine and in the company should ensure that the basic documentation that drives good sampling practice should be in order, i.e. COP, SOP and PTO. The champions should also ensure that operators are motivated by providing on-the-job and formal training. They should also perform regular audits and PTO. They should influence managers through informative presentations and reports to allocate capital to the development and maintenance of sound sampling equipment.

Generic audit checklists were developed from Appendices 10 and 11 in the article by Spangenberg (2007) to assist with the gathering of information during the visits. The checklists were successfully used during all the visits. Scores may be awarded per item to monitor performance over time. Hence it is recommended that the checklist for broken ore sampling (Table 6.2) and plant cross-stream sampling (Table 6.3) should be used by mineral resource managing personnel, i.e. metallurgists, geologists and evaluators in conducting structured investigations of the sampling installations.

Table 6.2 Broken ore sampling checklist

BROKEN ORE SAMPLING CHECKLIST						
Site: ________________________________ **Auditor(s)**: __________________________________ **Date**:___/___/___						
Standard	**No**	**Measure**	**Findings**			**Action by management**
			Score	**Std**	**Comments**	
Weightometer	1	**Weightometer**				
The calibration should be checked weekly by the mine/plant and quarterly by an accredited company/supplier. Calibrations should be done if necessary. All findings/work should be noted in a logbook. Weekly mechanical inspections should be done according to a planned maintenance program.	1.1	Calibration checked weekly by artisan?		3		
	1.2	Logbook completed?		1		
	1.3	Calibration by accredited company?		3		
	1.4	Logbook completed?		1		
	1.5	Weekly mechanical inspections as per planned maintenance program?		3		
	1.6	Is the weigh-frame clean?		3		
	1.7	Are all the idlers in working condition?		3		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Sampler	2	**Sampler**				
The minimum blade width should be not less than 3 times the top size on the belt. The rubber lip should be in a condition to execute a clean sweep. Material accumulating in the chute may cause chokes and cross-contamination. The sampler should be screened off for safety reasons.	2.1	Does blade width comply with minimum requirements?		2		
	2.2	Is rubber lip operational?		3		
	2.3	Does the cutter execute a clean sweep?		3		
	2.4	Does cutter cause spillage?		1		
	2.5	Any accumulation of material or spillage?		2		
	2.6	Is the sampler screened off?		2		
Detector	3	**Detector**				
Oversize material should be removed from the conveyor to prevent chokes and damage to the sampler and belt. Broken rocks should be loaded before the sampler to give it an opportunity to be sampled.	3.1	Is the oversize detector operational?		2		
	3.2	Are big rocks removed before the sampler?		2		
	3.3	Is the sampling process prevented until a big rock passed the cutter?		1		
	3.4	Do they break big rocks and load it onto the belt before the sampler?		2		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Operation	4	**Operation**				
The sampling frequency should have been statistically determined by calculating the error variance of the grade. The cutter should operate on a mass interval and not a time interval. The sampling frequency should be randomized within ±10% limits around the set value. The operator should note each sample label and corresponding integrator reading on a log sheet.	4.1	Does the sampler operate on a set mass interval? (Record frequency.)		3		
	4.2	Is the actual sampling randomized within limits?		1		
	4.3	Was the sampling frequency determined using a statistical method?		3		
	4.4	Does the sampler operate if there is no ore on the belt?		3		
	4.5	Is each cut collected separately?		3		
	4.6	Is each sample label recorded?		2		
	4.7	Is the weightometer reading recorded for each sample?		2		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Sample container	5	**Sample container**				
Dirt in a sample container is an indication that the complete sample is not prepared by the laboratory. Broken containers will cause spillage and cross-contamination. Water added to the samples will prolong the drying process. All the containers used to collect a cut should have the same label.	5.1	Are the containers in working condition?		3		
	5.2	Are the filled containers labeled?		3		
	5.3	Are the containers protected from rain?		2		
	5.4	Are the empty containers clean?		3		

Table 6.3 Plant cross-stream sampling checklist

PLANT CROSS-STREAM SAMPLING CHECKLIST						
Site: ________________________ **Auditor(s)**: ________________________ **Date**:___/___/___						
Standard	**No**	**Measure**	**Findings**			**Action by management**
			Score	**Std**	**Comments**	
Mass flow	1	**Mass flow**				
The calibration should be checked weekly by the plant personnel. A contract with an accredited company/supplier is recommended to verify the calibration and instrument operation. Calibrations should be done if necessary. All findings/work should be noted in a logbook.	1.1	Calibration checked weekly by artisan and Metallurgist?		3		
	1.2	Logbook completed?		1		
	1.3	Flow meter in working order?		3		
	1.4	Densitometer in working order?		3		
Sampler	2	**Sampler**				
Weekly mechanical inspections should be done according to a planned maintenance program. The operator should check that the sampler is in working order.	2.1	Weekly mechanical inspections as per planned maintenance program?		3		
	2.2	Shiftly inspection by operator?		3		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Collector	3	**Collector**				
The collector should comply to the requirements for a Correct Sampler as per the Theory of Sampling. The blades of a linear- and circular cross stream sampler are parallel and radial respectively. A sampler (and therefore the sample) is biased if one factor is found that may cause a bias.	3.1	Are the blades ≥10 mm apart?		3		
	3.2	Are the blades parallel / radial?		3		
	3.3	Is the collector clean?		3		
	3.4	Does the collector start from outside the stream?		3		
	3.5	Does the collector move through the entire stream?		3		
	3.6	Does the collector stop away from any splashing (check for splashing into collector and position of secondary collectors)?		3		
	3.7	Does the collector move at constant speed inside the stream?		3		
	3.8	Does the collector reach constant speed before entering the stream?		3		
	3.9	Does the collector move at less than 0.6 m/s?		3		
	3.10	Does the collector accept the complete flow (check for spillage/out-flow)?		3		
	3.11	Does the collector accept the entire crosscut of the stream?		3		
	3.12	Is the flow non-turbulent at the point of sampling (check for splashing over collector)?		3		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Operation	4	**Operation**				
The sampling frequency should have been statistically determined by calculating the error variance of the grade. The cutter should preferably operate on a mass interval and not a time interval. The flow is usually constant and a time interval is acceptable. The number of increments and mass flow per sample can be used to calculate the amount of sample that should have been received – the contrary will indicate a faulty sampler. Samples collected and problems experienced should be listed.	4.1	Does the sampler operate on a set mass interval? (Record frequency.)		3		
	4.2	Does the sampler operate on a set time interval? (Record frequency.)		3		
	4.3	Does the sampler execute a single cut per cycle?		3		
	4.4	Is the number of cuts recorded?		2		
	4.5	Is the mass flow integrator reading recorded per composite sample?		2		
	4.6	Does the operator complete a checklist and/or log sheet?		2		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Secondary sampler	5	**Secondary sampler**				
The secondary sampler should start when the primary cut is initiated. After sub-sampling it should stop in such a position that the collectors are out of the stream before the primary cleaning cycle is initiated. The secondary cleaning cycle should start when the sample containers are removed – this should be done at least twice per shift.	5.1	Is the sampler of the Vezin type?		3		
	5.2	Is the down pipe intact?		3		
	5.3	Does the sampler provide for a duplicate sample?		2		
	5.4	Does the sampler stop out of the stream after sub-sampling?		2		
	5.5	Are the collector openings radial?		3		
	5.6	Are the collectors clean?		3		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Cleaning system	6	**Cleaning system**				
The collectors will choke if the cleaning system is not in operation.	6.1	Is the primary cleaning system operational?		3		
The volume of the sample will increase if the spray water is added to	6.2	Is the secondary cleaning system operational?		3		
the sample – the calculated frequency may not be decreased to cater for the	6.3	Does the cleaning start after sub-sampling?		2		
additional water -- the sample cannot be used to determine density.	6.4	Is a set of spray nozzles installed on both sides of the stream?		3		
	6.5	Is potable water used for cleaning?		3		
	6.6	Does the spray water cover the complete length of the blades?		3		
	6.7	Is the primary collector clean?		3		
	6.8	Are the secondary collectors clean?		3		

Standard	No	Measure	Findings			Action by management
			Score	**Std**	**Comments**	
Sample preparation	8	**Sample preparation**				
High- and low grade samples should be prepared separately to prevent contamination. The complete sample should be contained during preparation. Samples due for sulphur analysis should be dried at 80°C; otherwise a temperature of 200°C is allowed.	8.1	Are the high- and low grade samples prepared separately?		3		
	8.2	Is the general housekeeping good?		2		
	8.3	Are the filter presses clean?		3		
	8.4	Does any sample leak from the base of the filter drum?		3		
	8.5	Is the first filtrate collected after ±10 sec?		3		
	8.6	Is each sample washed 4 times before drying?		3		
	8.7	Are all solids recovered from the filter paper and filter drum?		3		
	8.8	Are the drying pans/ trays clearly marked?		3		
	8.9	Are all lumps broken?		3		
	8.10	Is the coarse material on the screen added to the sample (or discarded)?		3		
	8.11	Are the oven temperatures set at 80°C or 200°C?		3		

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APPENDIX A: Spread Sheets for Analysis of Audits

Included on compact disc:

- Summary spread sheet of potential influence of sampling errors.
- Individual spread sheets of all mines visited. Three companies requested that the names of the mines in their ownership should remain anonymous. The identity of the operations that were visited is protected as the purpose of the study is to get an understanding of the general status of sampling practices. Each mine received a report which included the original audit checklists.